

THE OLD RED SANDSTONE OUTLIERS
OF GARRIE AND RHYNIE, ABERDEENSHIRE.

VOLUME 2

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APPENDICES

APPENDIX I.Analysis of Conglomerate Composition.

In theory, by analogy with point counting procedures, the analysis of conglomerate composition involving 13 rock types would involve identification of over 1000 individual pebbles. As such a task would be very time consuming and even more tedious an assessment of the possible means of evaluating composition have been considered.

Clearly, for practicality, the total number of pebbles counted in each sample must be reduced, and the prime concern must therefore be to ensure that the sample measured is representative of the whole and that the results are purely objective.

Several methods of sampling were considered :

1. measurement of a fixed total number of clasts,
2. measurement of all clasts in a pre-defined area,
3. erection of a grid, and selection of intersections on grid as sample points using random number tables,
4. erection of a grid of fixed size, and identification of clasts at grid intersections.

Although each procedure produced relatively consistent results, the first two methods were considered to be very much open to operator errors. When a free selection of clast types or sizes is given, the first two methods would allow 'easy' clasts to be preferentially selected, or smaller 'difficult' clasts to be rejected. The third method is one frequently applied to overcome sampling problems, but as a field technique, proved to be too cumbersome. The fourth method satisfied most requirements.

Essentially, a grid was constructed (a perspex template for

finer grades, and a 'square' string net for coarser grades) and a positive identification of clast type made at each intersection. Where intersections coincided with clast contacts, the site was rejected and the grid area extended such that a total of 100 clasts were measured for every sample station.

By this method an unbiased and relatively accurate assessment of conglomerate composition was achieved, and results were found to be quite reproducible. In order to reduce subjective errors further, the results were not computed or recorded in clast type groups until a complete stratigraphic section had been sampled.

Sample points were, as far as possible, made at equally spaced stratigraphic intervals.

APPENDIX II.Separation and Analysis of Clay Minerals.

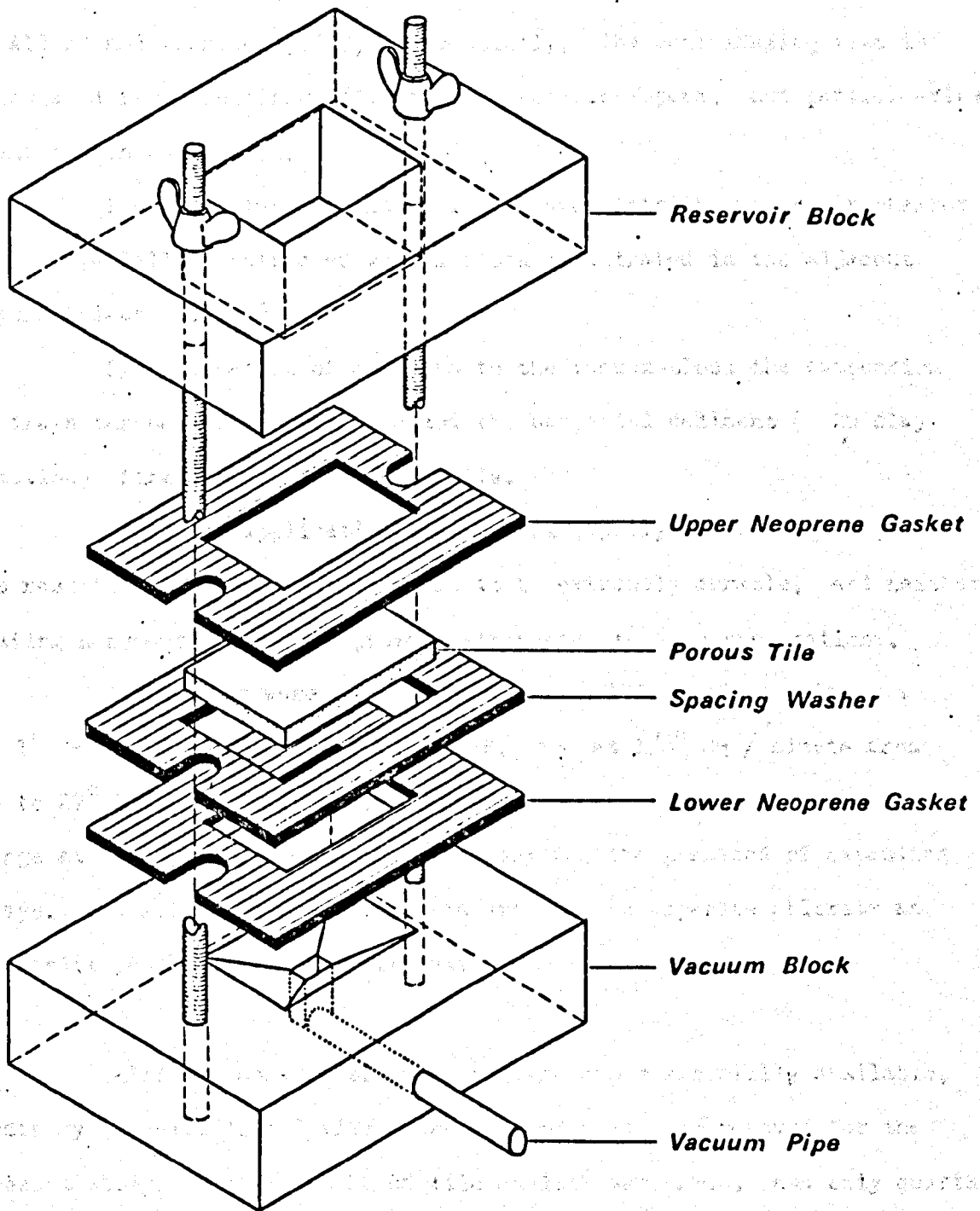
Clay minerals show an integral series of reflections, most useful over the range $30\text{\AA} - 3.5\text{\AA}$. During the present study, X-ray diffractograms of whole rock samples were obtained by a method outlined below.

Several methods of preparation of X-ray diffraction mounts are at present in use, the following methods were considered:

- (i) gravity settling of the $< 2\mu$ fraction onto a microscope slide,
- (ii) slurring of the $< 2\mu$ fraction onto a microscope slide,
- (iii) centrifuging the $< 2\mu$ fraction directly onto a microscope slide,
- (iv) separating and drying the $< 2\mu$ fraction and pressing this into a pellet,
- (v) separating the $< 2\mu$ fraction and adhering this onto a porous silica tile.

All of these methods were found to be quite adequate, none giving better results than others. Methods 1 and 3 produce well-oriented preparations, and theoretically allow preferential emphasis of the c-axis reflections. Overall, methods 1 to 4 were found to be extremely slow, and the resulting mount delicate, particularly if any attempt is made to heat or glycolate the separations. Method 5 was developed during this study, and although non-oriented mounts are produced, the resulting diffractograms proved adequate and highly reproducible. The procedure employed is as follows:

1. whole rock samples crushed and dispersed in distilled water containing a deflocculating agent (2% sodium hexametaphosphate).



Block diagram of the 'vacuum apparatus' developed during the routine the present study.

Dispersion is assisted by use of an ultrasonic bath.

2. The resulting suspension is centrifuged in a manner described by Allman and Lawrence (1972). Essentially, the centrifuging time is calculated from centrifuge dimensions, rotation-speed, and particle-size remaining in suspension.

3. The resulting suspension is decanted into the reservoir chamber of the specially constructed vacuum block illustrated in the adjacent figure (figure A.II.1).

4. By application of a vacuum to the vacuum-block the suspension is drawn through the porous tile and the suspended sediment (2μ clay fraction) firmly adhered onto the tile.

5. Continued application of a vacuum rapidly dries the tile, and the resulting mounts have been found to be extremely durable, and neither heating nor glycolation have proven detrimental to such preparations.

6. The mounts were glycolated (Brunton 1955) after being run at $1^\circ 2\theta$ / minute from $3^\circ 2\theta$ to $35^\circ 2\theta$, and at $1/8^\circ 2\theta$ / minute from 24 to $27^\circ 2\theta$. After glycolation, the mount was re-run over the whole range at $1^\circ 2\theta$ / minute in order to test for the presence of expanding clays. The slow scan procedure was employed to separate chlorite and kaolinite peaks rather than alternative heating methods.

Although ceramic tiles or sinters are commercially available, ordinary domestic 'bath' tiles were cut and the glaze removed for the present study. Random checks of tile quality were made, and only quartz peaks detected in the diffractograms.

No universally accepted system has been developed for the routine quantitative analysis of clay mineral mixtures, essentially due to the variability in chemical and structural properties, the refracting ability being largely dependant on composition, polytype, degree of crystallinity, and even grain-size.

APPENDIX III.Chemical Analysis Procedures.

During the study of the red-beds of the Gamrie and Rhynie Outliers, whole-rock analysis of sandstones, siltstones, and mudstones were undertaken in order to determine the following major elements as oxides. Two major procedures were necessary:

- (i) the determination of ferrous-iron,
- (ii) the determination of total-iron (as ferric-iron),
and the determination of MgO, MnO, CaO, K₂O, Na₂O.

A. Procedure adopted for the determination of ferrous iron.

1. 3 - 50mg. of crushed sample weighed into a perspex vial.
2. Add 0.1ml. of 0.14N ammonium vanadate solution plus 1ml. hydrofluoric acid. (The ammonium vanadate causes the immediate oxidation of all Fe² to Fe³ and the liberation of an amount of V⁴ equivalent to the amount of Fe³ generated.)
3. Allow to stand for up to 72hrs. to complete the decomposition (ie. no gritty residue, but various light "fluffy" fluorides may be precipitated.)
4. Complex the hydrofluoric acid by the addition of 5ml. of beryllium sulphate solution (50% weight:volume). Shake (on a shaker hotplate) to dissolve the fluorides (up to 2hrs.).
5. Wash into a 100ml. volumetric flask containing 5ml. Dipyrldyl solution (0.15 % weight:volume) plus 10ml. (50 % weight:volume) ammonium acetate diluted to approximately 50ml. with distilled water. Make up to volume, shake, and stand for at least 30 mins.
(The ammonium acetate brings the pH to approx. 5, where the reverse reaction from 2 above occurs. In the presence of the Dipyrldyl

- solution, the regenerated Fe^{2+} causes proportionate reddening).
6. The absorbance of this solution is read at 525nm. in 1cm. cells against water in an absorption spectrophotometer.
 7. If the absorbance is greater than 0.8, the solutions are diluted 25ml. : 50ml. and re-read.

SOLUTIONS USED.

- A. Beryllium Sulphate (50 % weight:volume) dissolve 250g Beryllium Sulphate tetrahydrate (Analar) in water and dilute to 500ml.
- B. Ammonium Acetate (50 % weight:volume) dissolve 250g Ammonium Acetate (Analar) in water and dilute to 500ml.
- C. 2:2' Dipyridyl (0.15 % weight:volume) dissolve 0.75g Dipyridyl (Analar) in water and dilute to 500ml.
- D. 0.14N (approx) Ammonium Vanadate dissolve 8.2g ammonium metavanadate (Analar) in 500ml. 2N sulphuric acid. (Prepare the 2N sulphuric acid by adding 28ml. conc. sulphuric acid slowly to 300ml water, mixing and allowing to cool, and then diluting to 500ml.).

B. Proceedure adopted for the determination of major elements as oxides.

1. 100mg. of crushed sample weighed into a teflon 'bomb', moisten with 0.5ml aqua-regia and add 5ml hydrofluoric acid.
2. Insert 'bomb' into steel case and heat at $110 - 120^{\circ}\text{C}$ for $2\frac{1}{2} - 3$ hrs.
3. When cool, transfer contents into a polystyrene vial containing 2g. boric acid, wash lid and sides of container scrubbing with a polythene rod. (Do not exceed 70ml. total volume)
4. Warm gently to dissolve fluorides.
5. Cool solution and dilute to 200ml in a volumetric flask. Transfer immediately to plastic bottle.

6. The solutions are measured in standard concentrations against standards on an atomic absorption spectrophotometer.

CHAPTER I

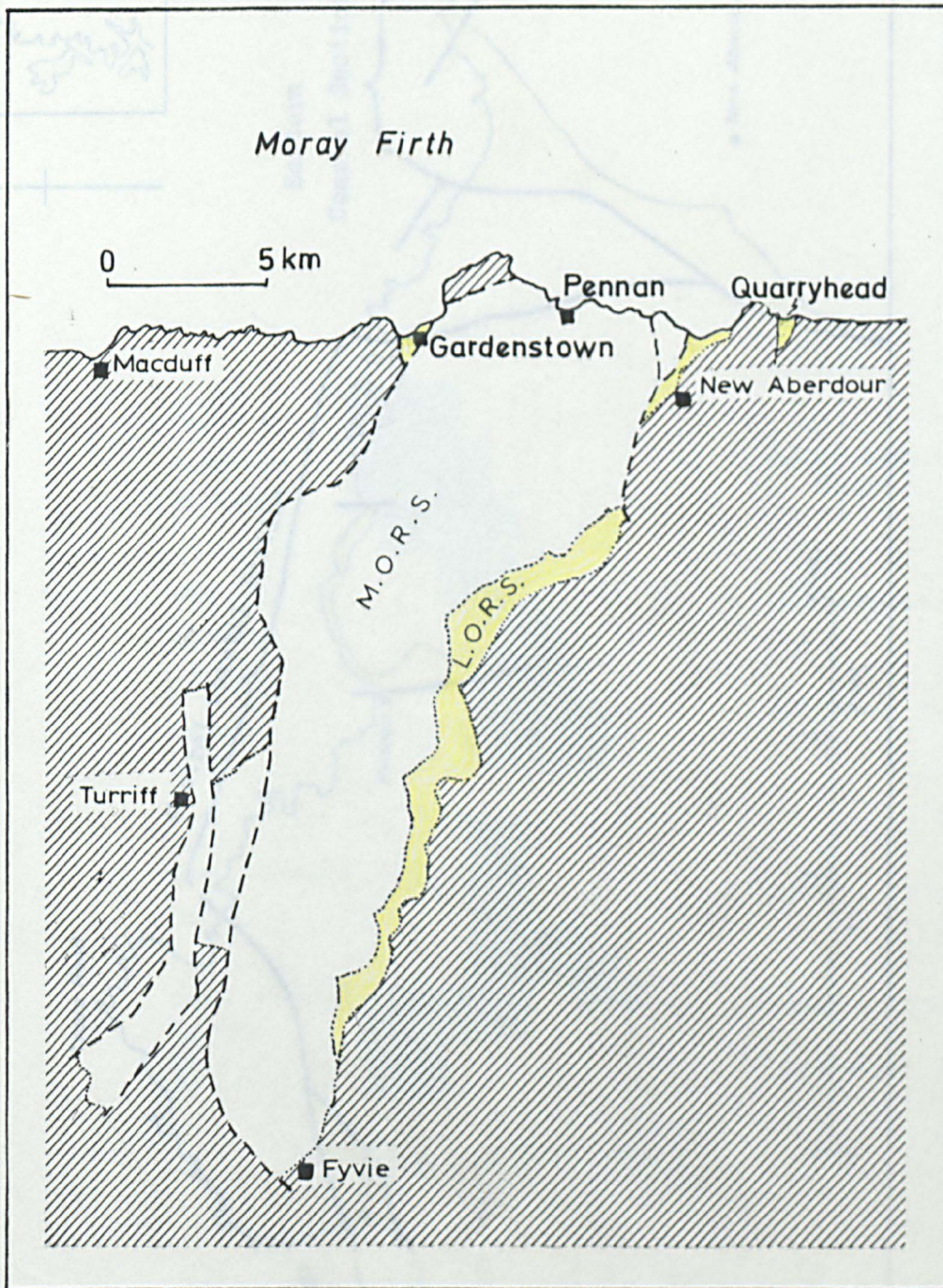


Figure 1.1

Outcrop map of the Gamrie Outlier showing the distribution of Lower and Middle Old Red Sandstone sediments.

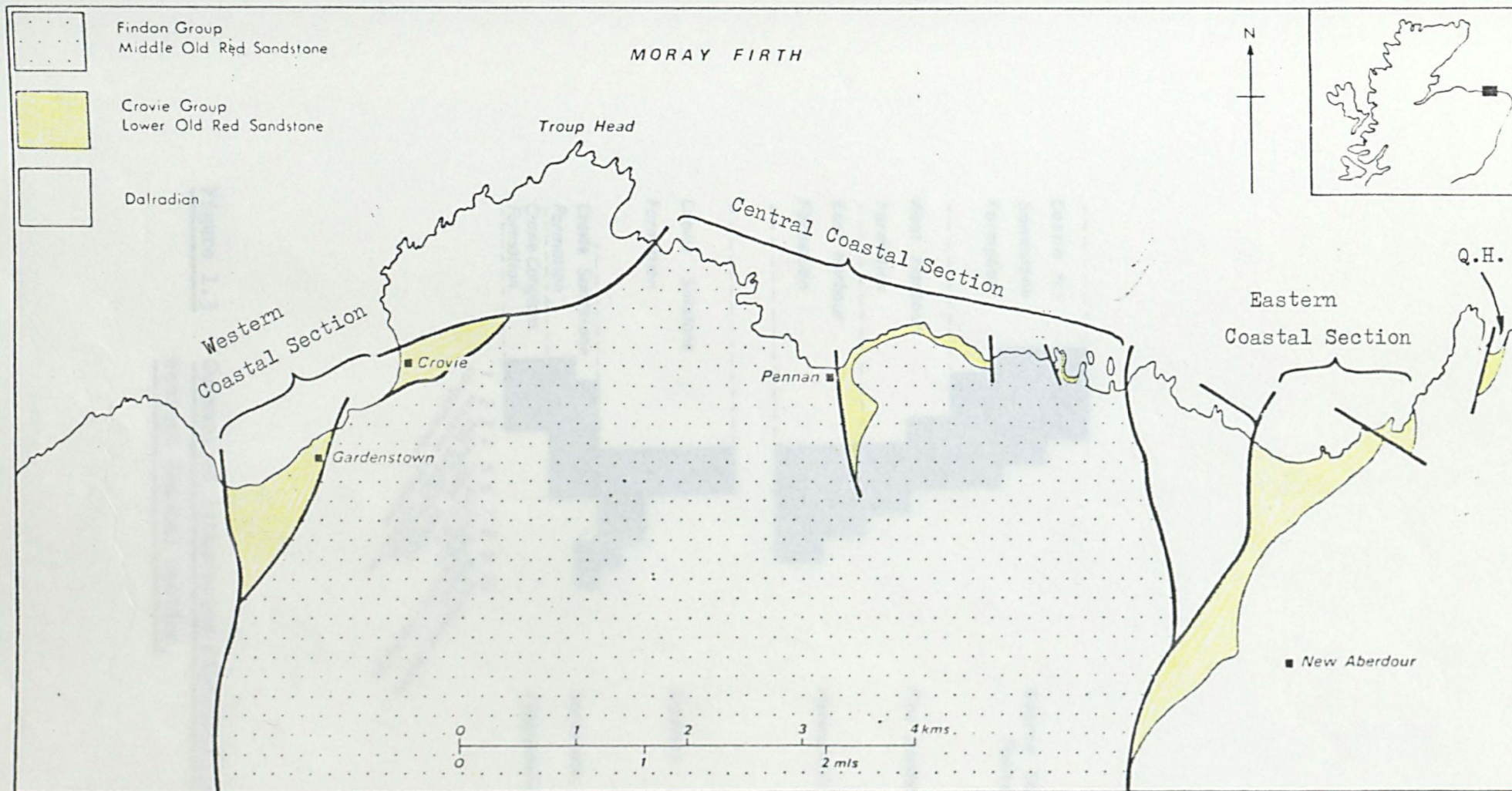


Figure 1.2 Generalised map of the northern portion of the Gamrie Outlier showing the location of the four major fault bounded coastal sections.

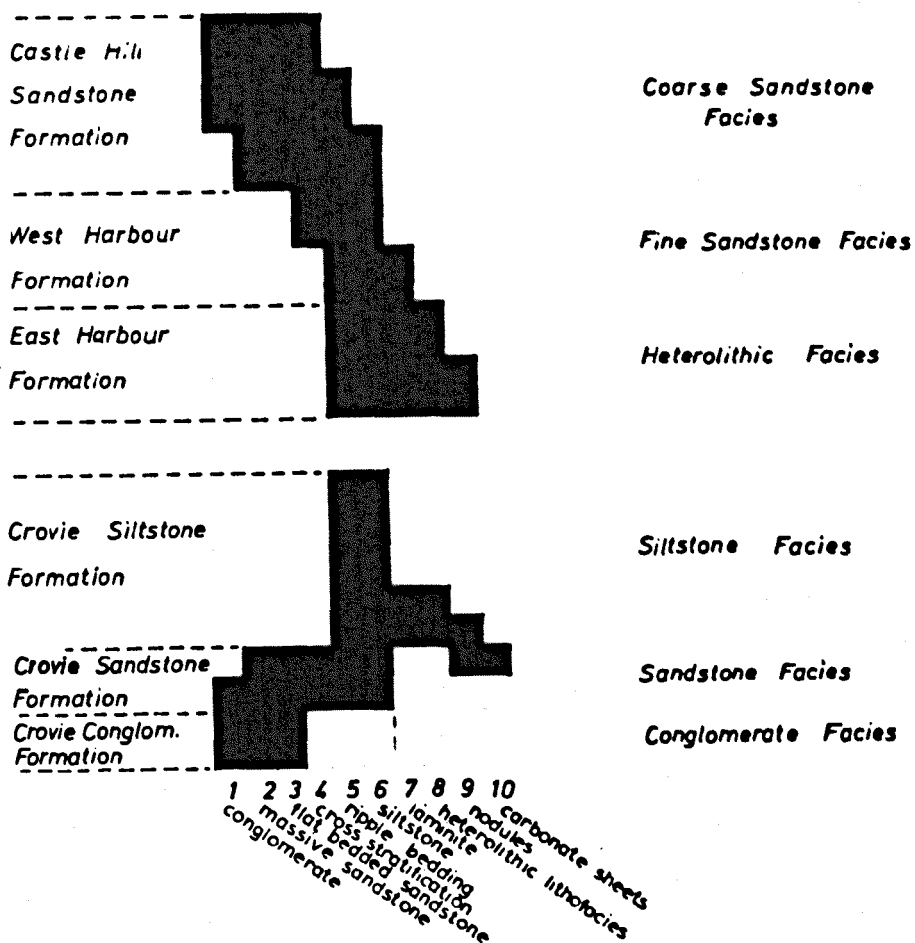


Figure 1.3 Summary of lithofacies distribution in the Western Coastal Section.

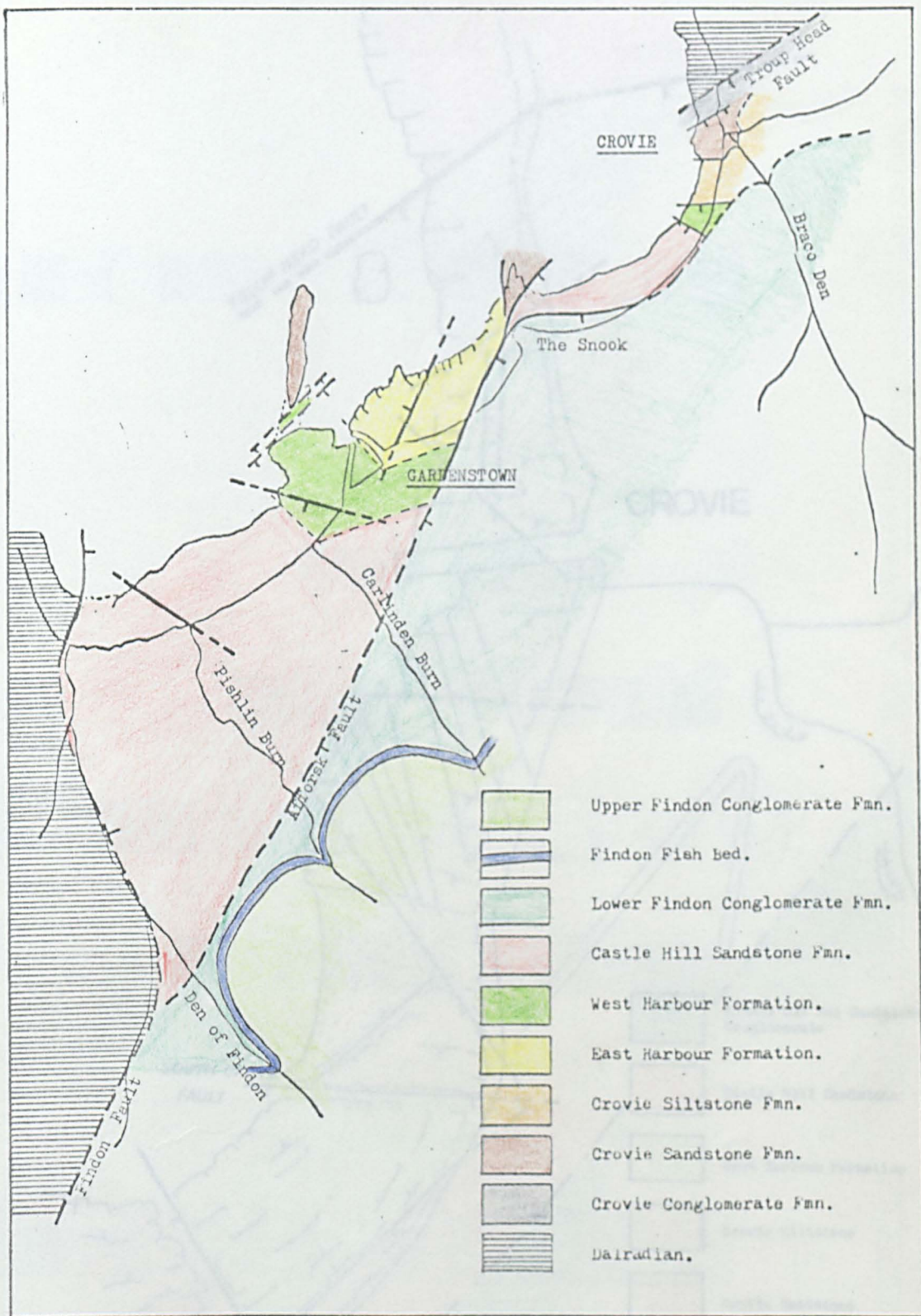


Figure 1.4

Geological map of the Western Coastal Section.

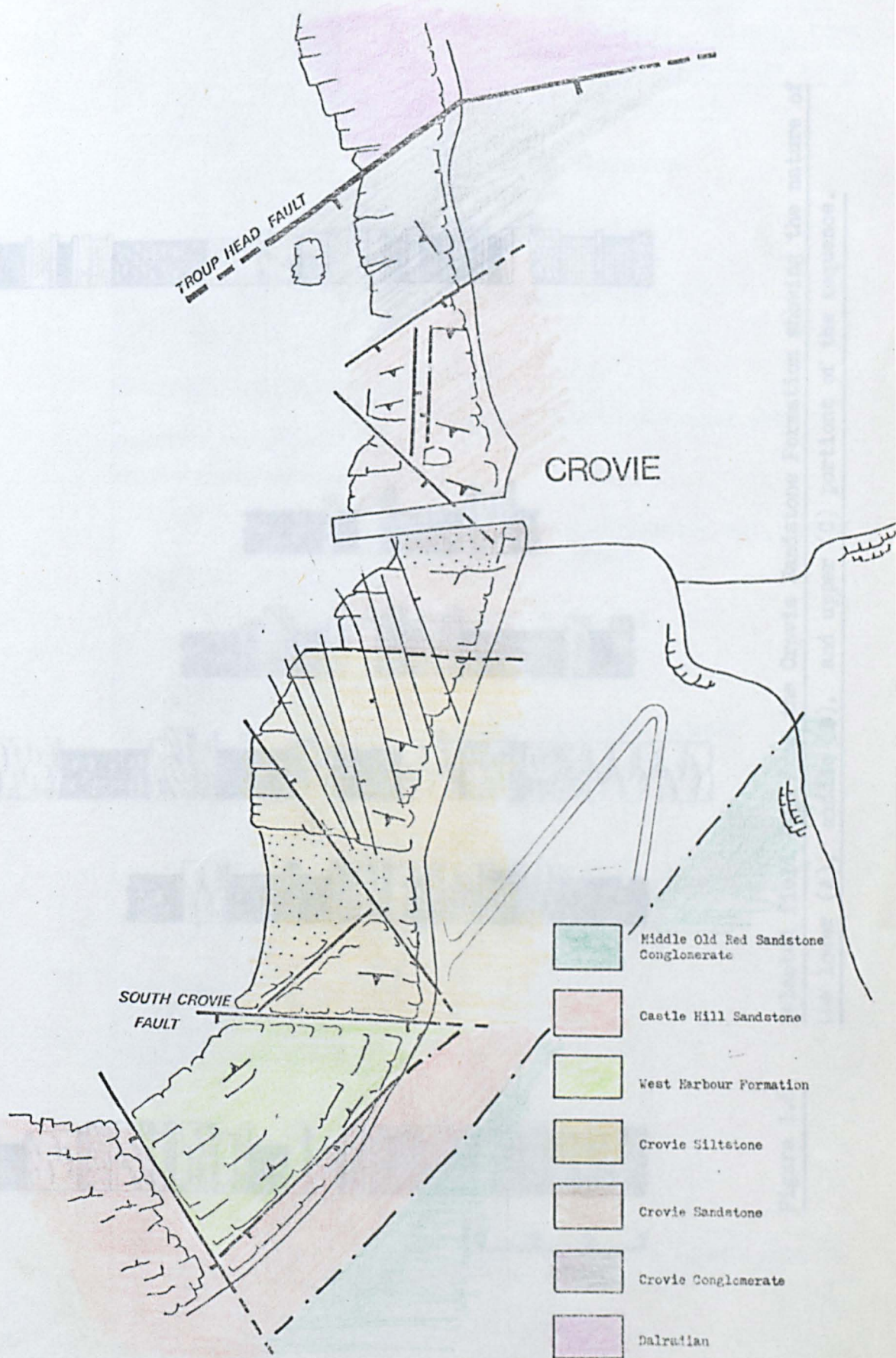


Figure 1.5 Geological map of the Crovie Coastal Subsection.

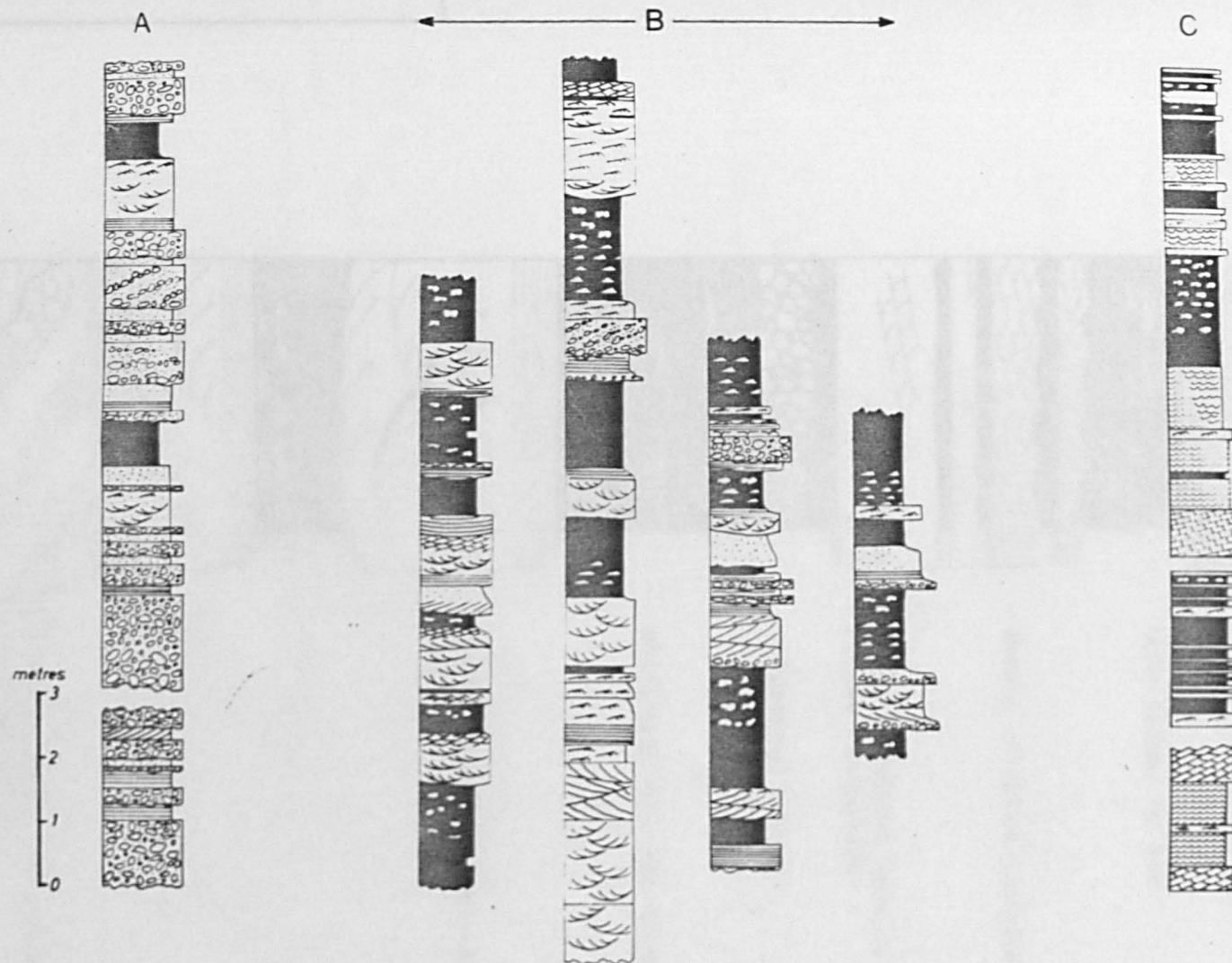
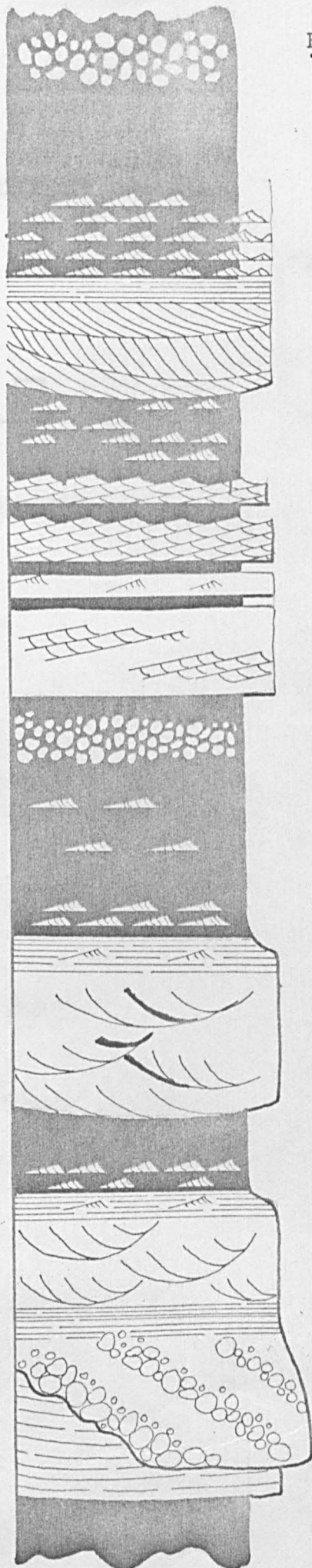


Figure 1.6

Selected field logs from the Grovie Sandstone Formation showing the nature of the lower (A), middle (B), and upper (C) portions of the sequence.

Figure 1.7 Detailed field log
through a portion of the
Grovie Sandstone Fmn.
sequence, showing form
and relationships within
the sequence.



flat bedded sandstone.

cross stratified sst.

thin lenses of sst.

sheets of cross-laminated sst.

sheet of almost massive sst, rare
ripple lamination.

calcareous nodules.

siltstone with sst lenses.

cross-stratified sst with silt
films on foresets.

conglomerate, with crude cross-
stratification.

channel erosion.

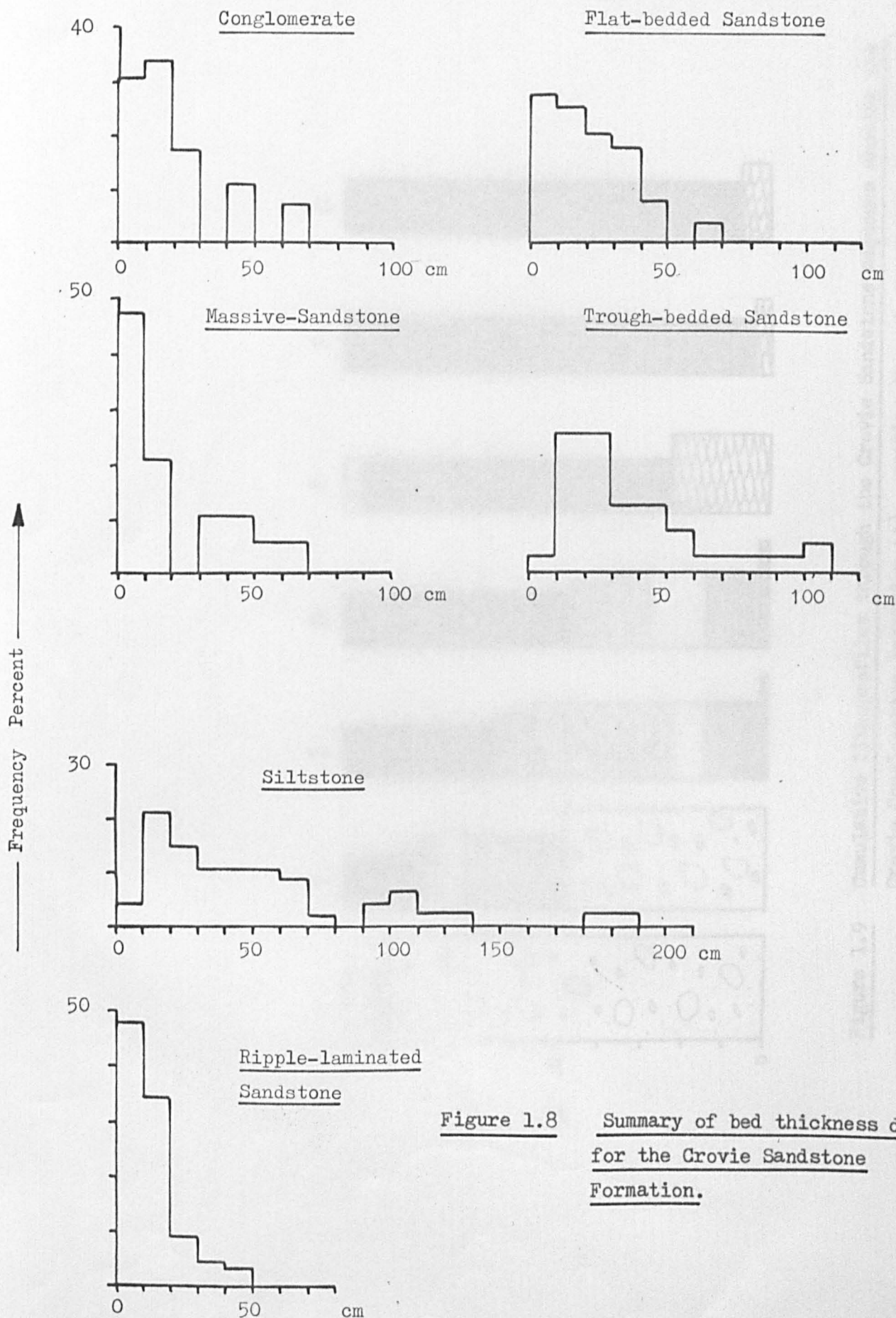


Figure 1.8

Summary of bed thickness data
for the Grovie Sandstone
Formation.

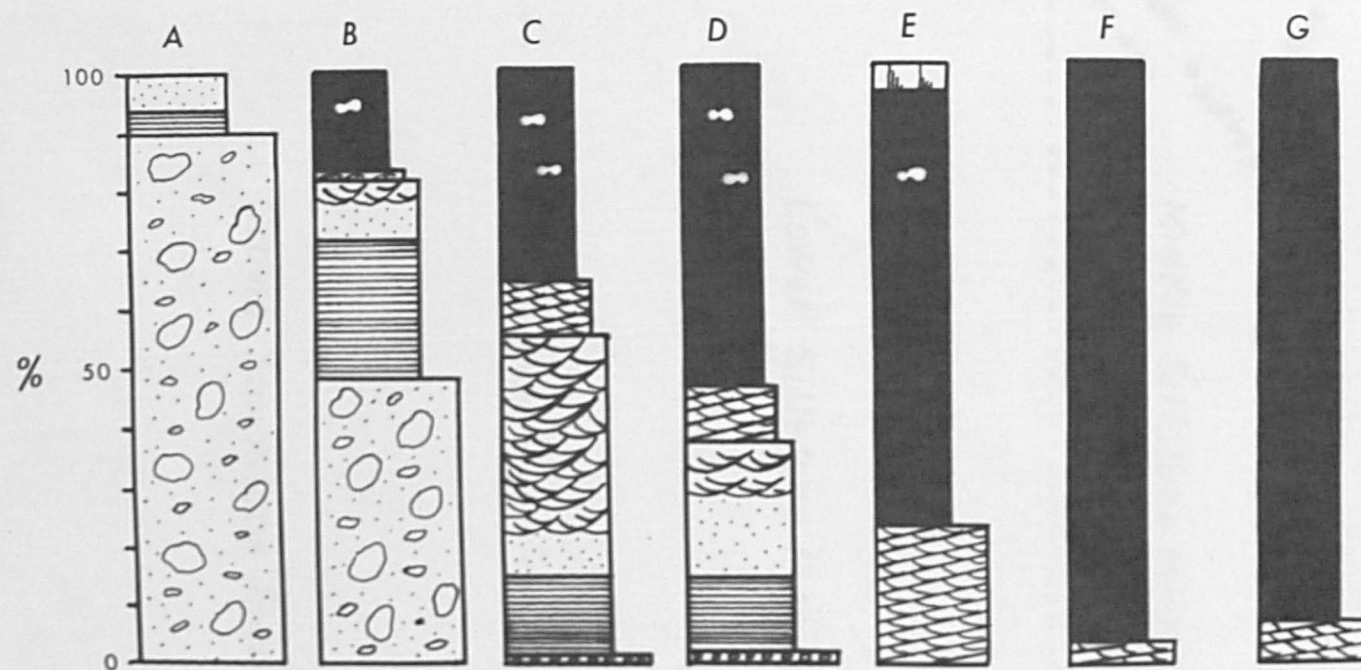


Figure 1.9 Cumulative lithoprophiles through the Grovie Sandstone sequence showing the Grovie Conglomerate Formation (A), grading through the Grovie Sandstone Fmn (B,C,D) into the Grovie Siltstone Formation (E,F,G).

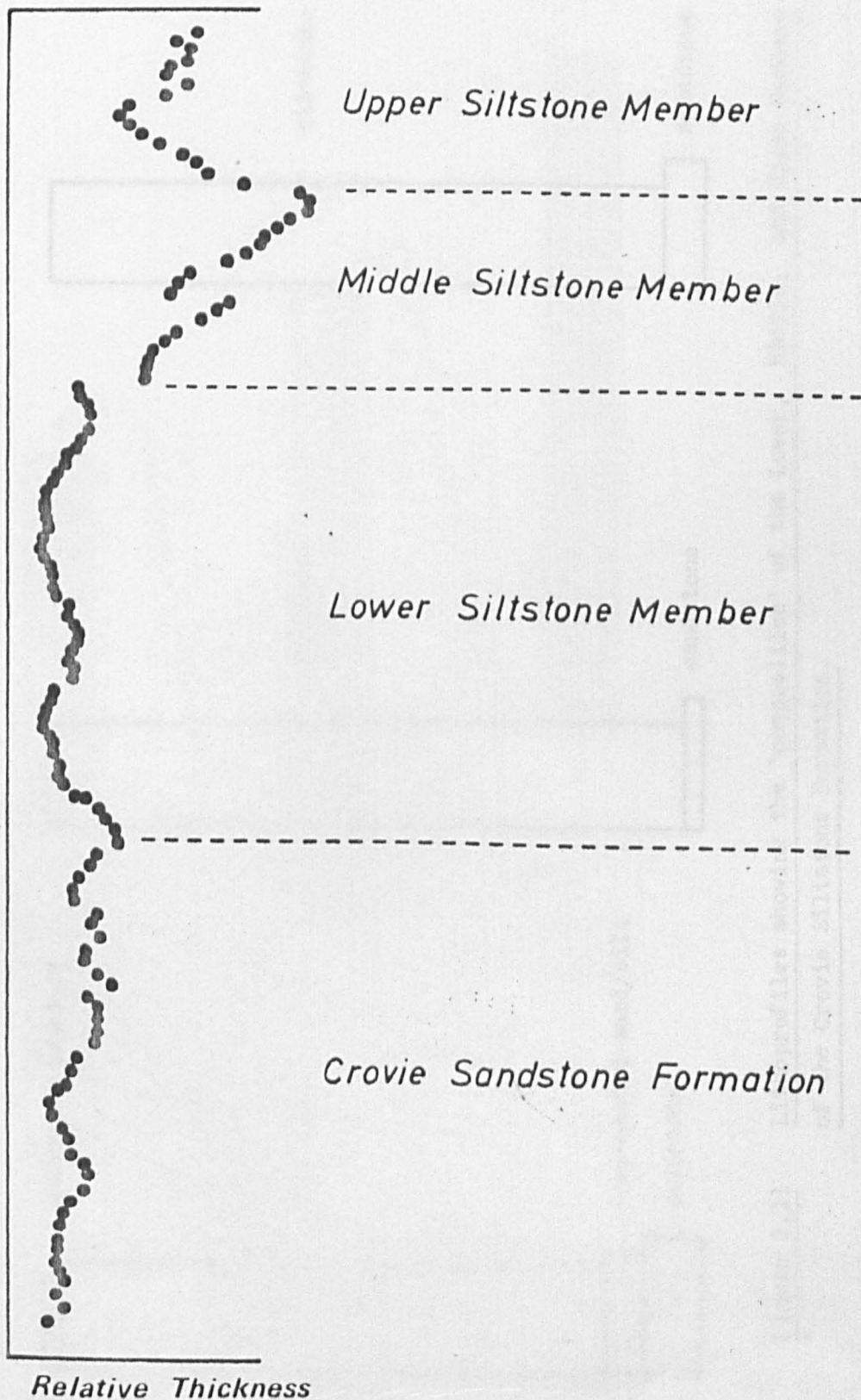


Figure 1.10 'Smoothed' time trend of siltstone thickness
throughout sediments of the Crovie Coastal Subsection.

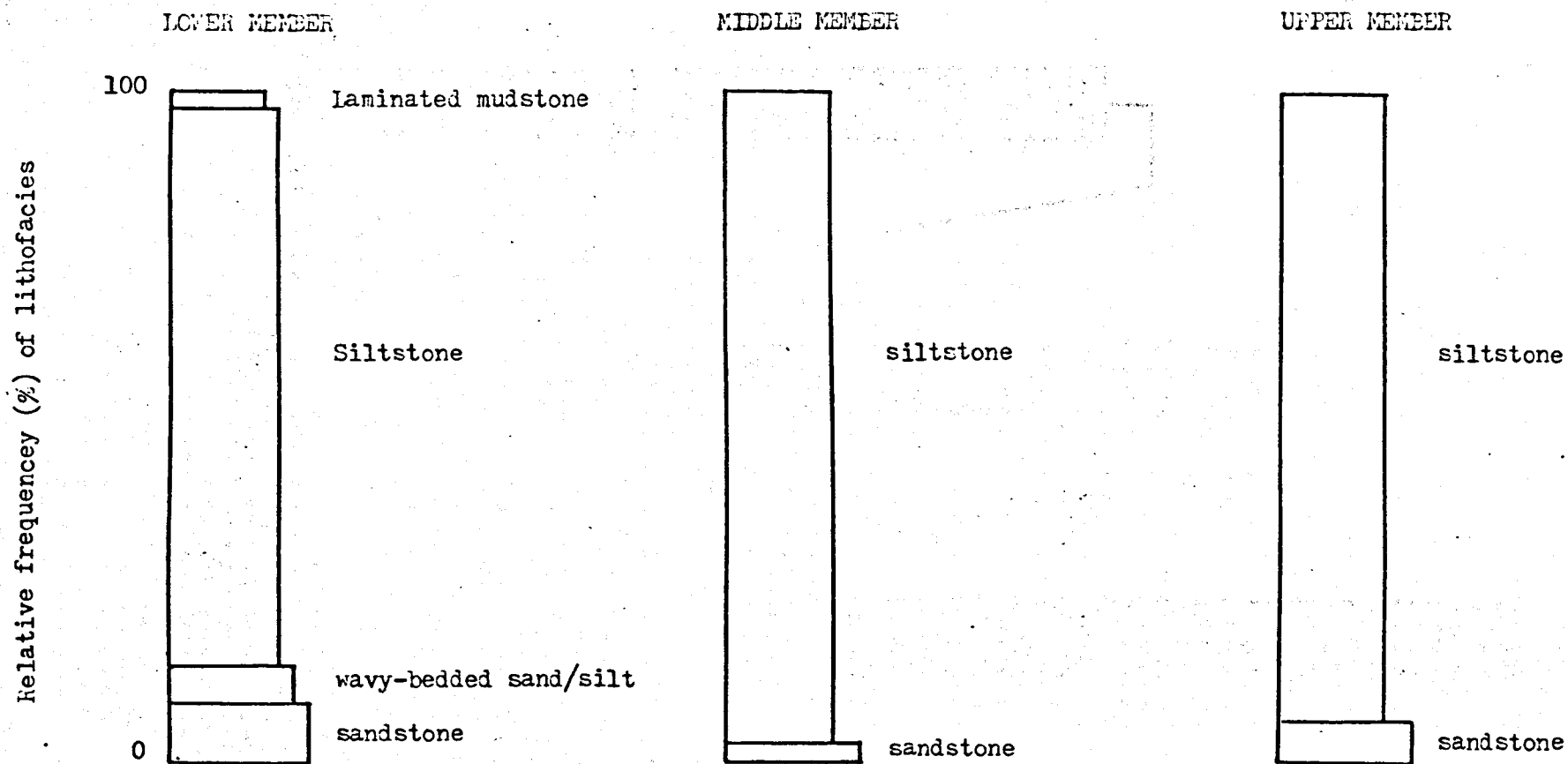


Figure 1.11 Lithoprofiles showing the 'composition' of the Lower, Middle, and Upper Members of the Crovie Siltstone Formation.

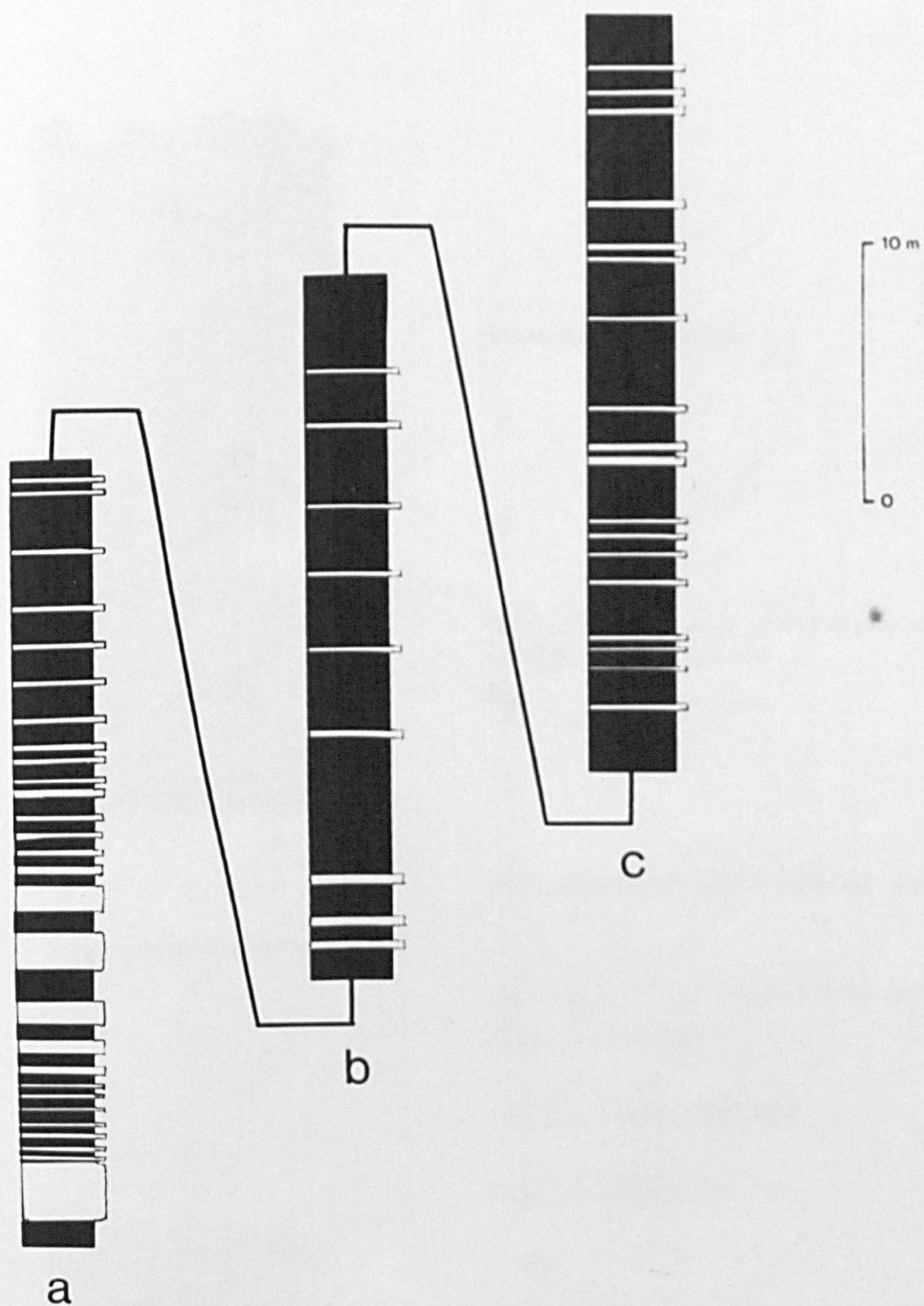


Figure 1.12 Selected field logs through the Grovie Siltstone Formation demonstrating the nature of the lower (A), middle (B), and upper (C) members.
(log shows distribution of sandstones and siltstones).

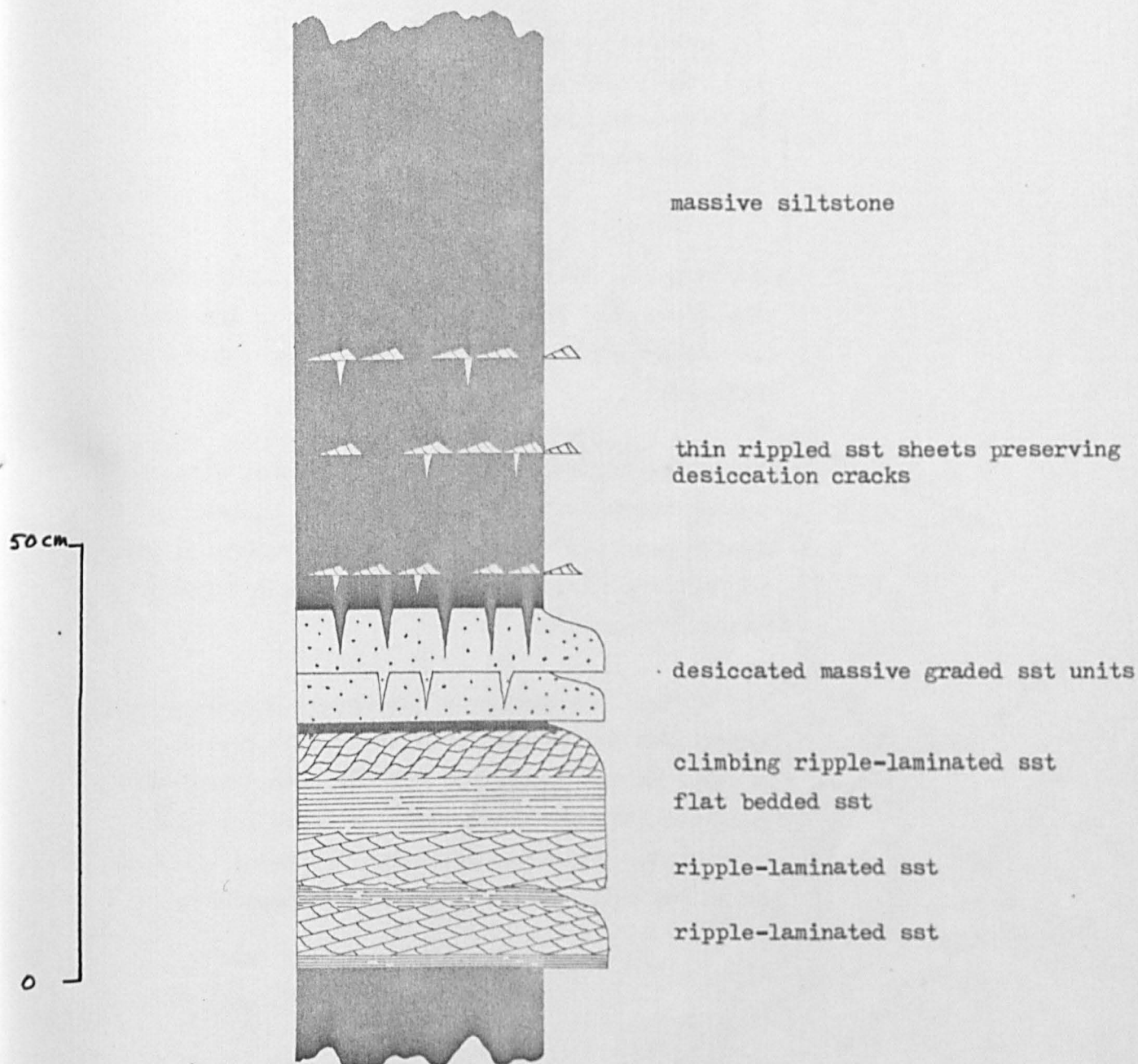


Figure 1.13 Detailed field log through a portion of the Grovie Siltstone Formation showing the general relationships between the coarse and fine unit alternation.

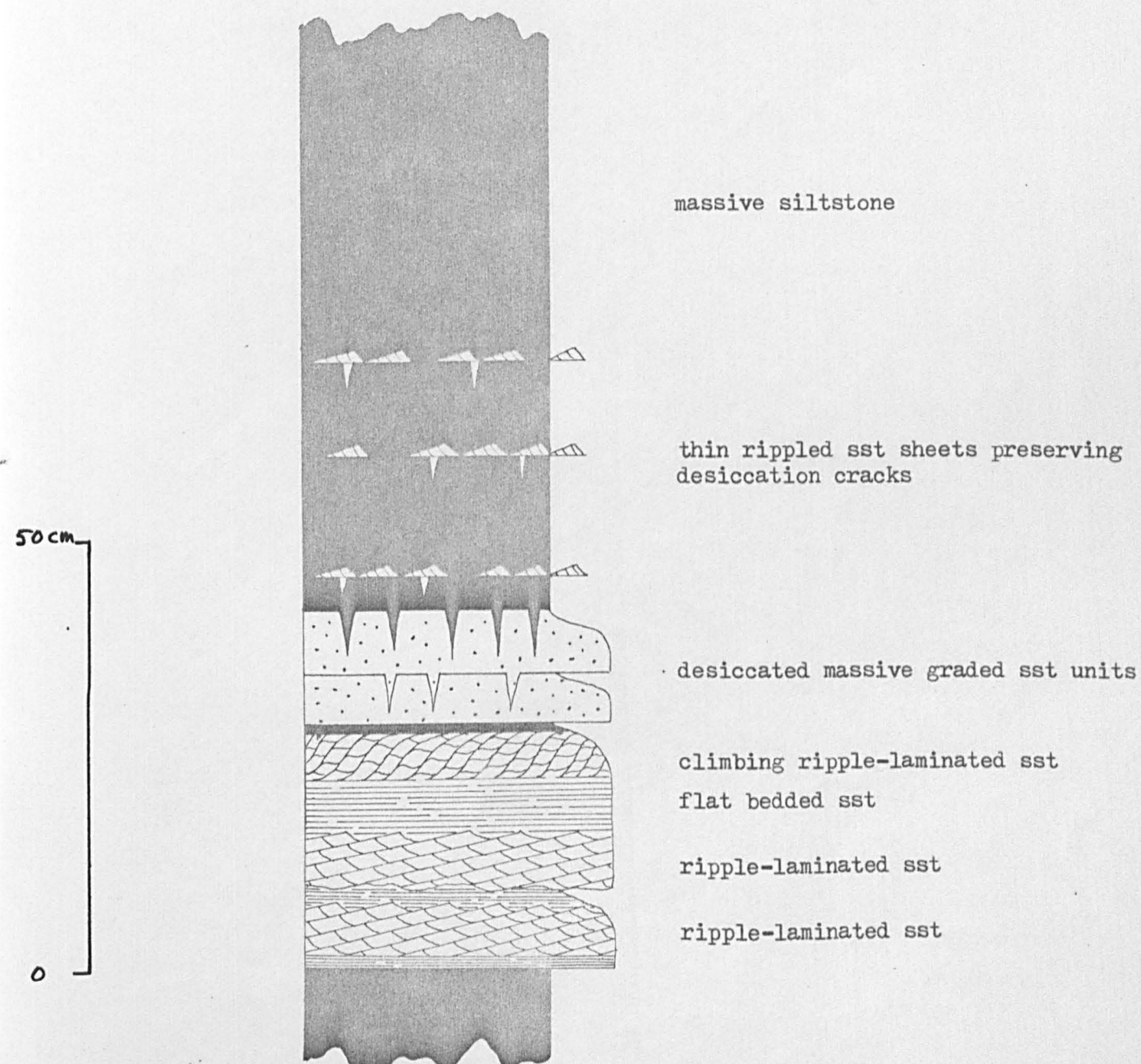


Figure 1.13 Detailed field log through a portion of the Crovie Siltstone Formation showing the general relationships between the coarse and fine unit alternation.

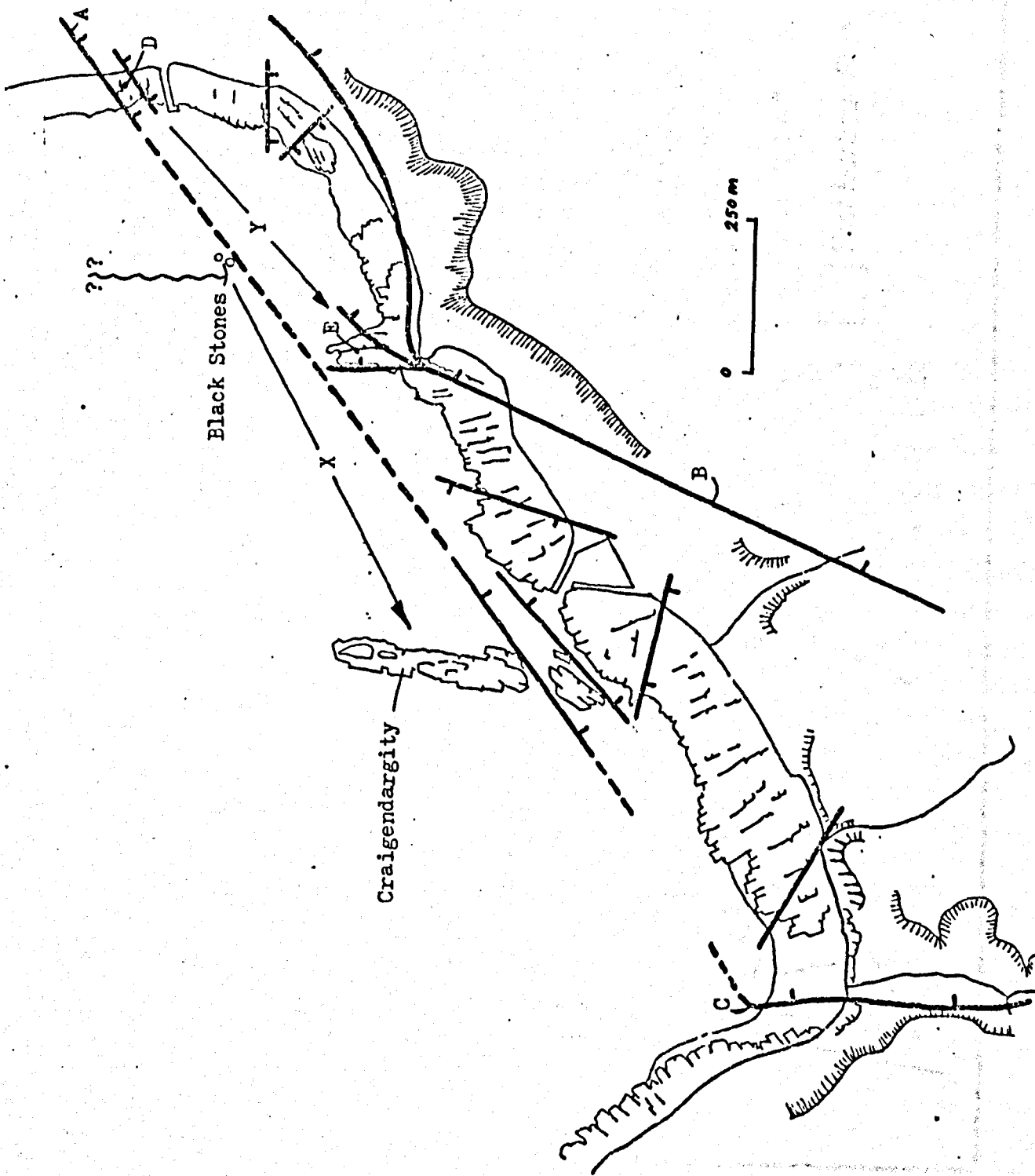
Figure 1.14 Map showing the generalised structure of
the Western Coastal Section, namely :-

- (A) the Troup Head Fault,
- (B) the Afforsk Fault,
- (C) the Findon Fault.

It is likely from the parallel fault trends that the Troup Head Fault passes as shown to the south of Craigendargity and Black Stones (an outcrop of Dalradian).

It is therefore considered possible that a 'normal' unconformity may exist between Black Stones and Craigendargity, thus allowing a considerable thickness of Crovie Sandstone (exposed at Craigendargity) to exist. (sequence X)

Similarly, the strike of the Crovie Conglomerate(D) is similar to the strike of the Crovie Sandstone exposed at the Snook (E). It is also therefore possible that these two short sections are also connected, providing a similar thickness of Crovie Sandstone / Crovie Conglomerate. (sequence Y)



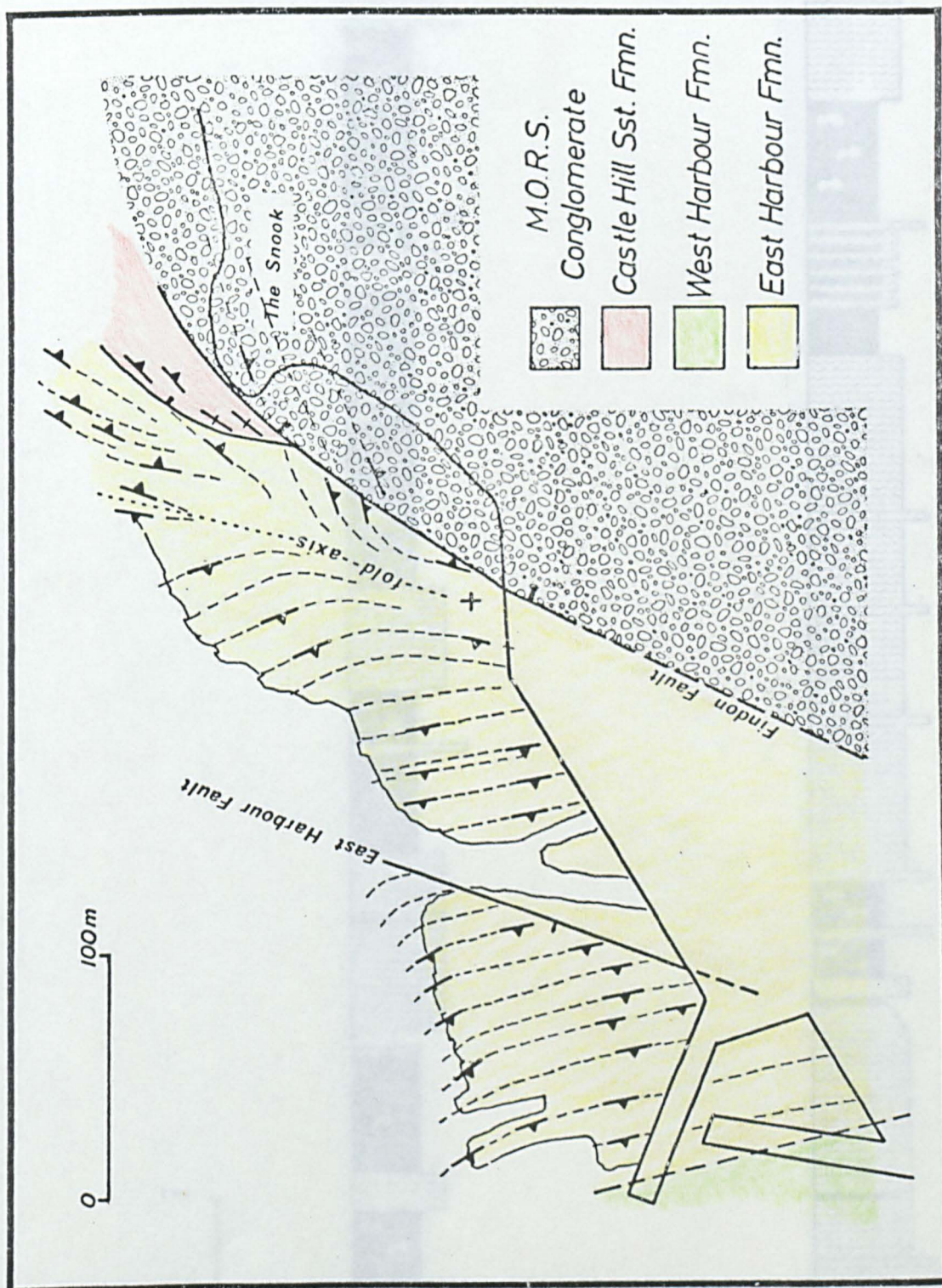


Figure 1.15 Geological map of the Gardenstown Subsection between Gardenstown Harbour and the Snook.

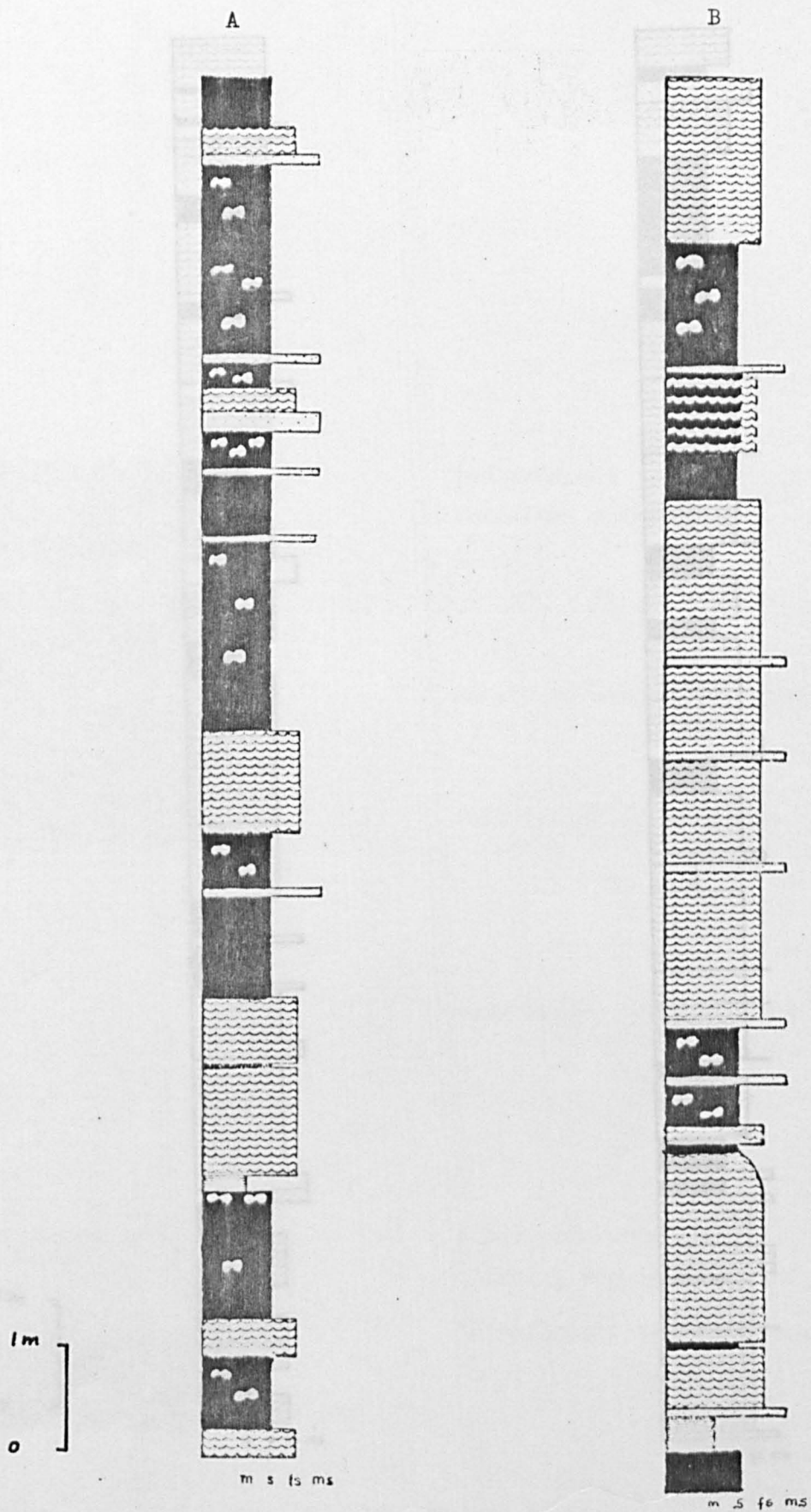


Figure 1.16 Selected field logs through the East Harbour Formation (lower member).

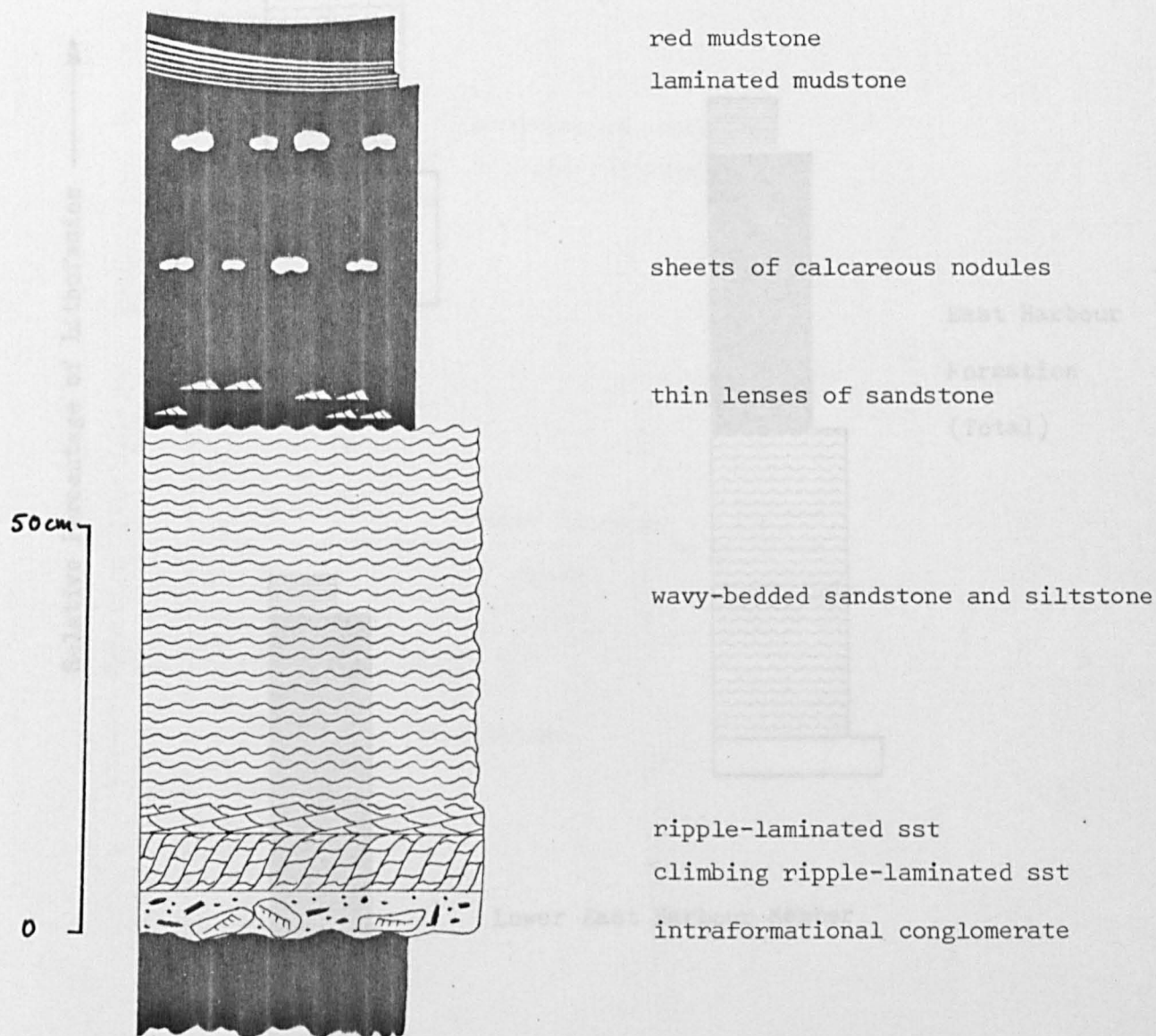


Figure 1.18 Detailed field log through a portion of the East Harbour Formation showing general lithofacies relationships within the sequence.

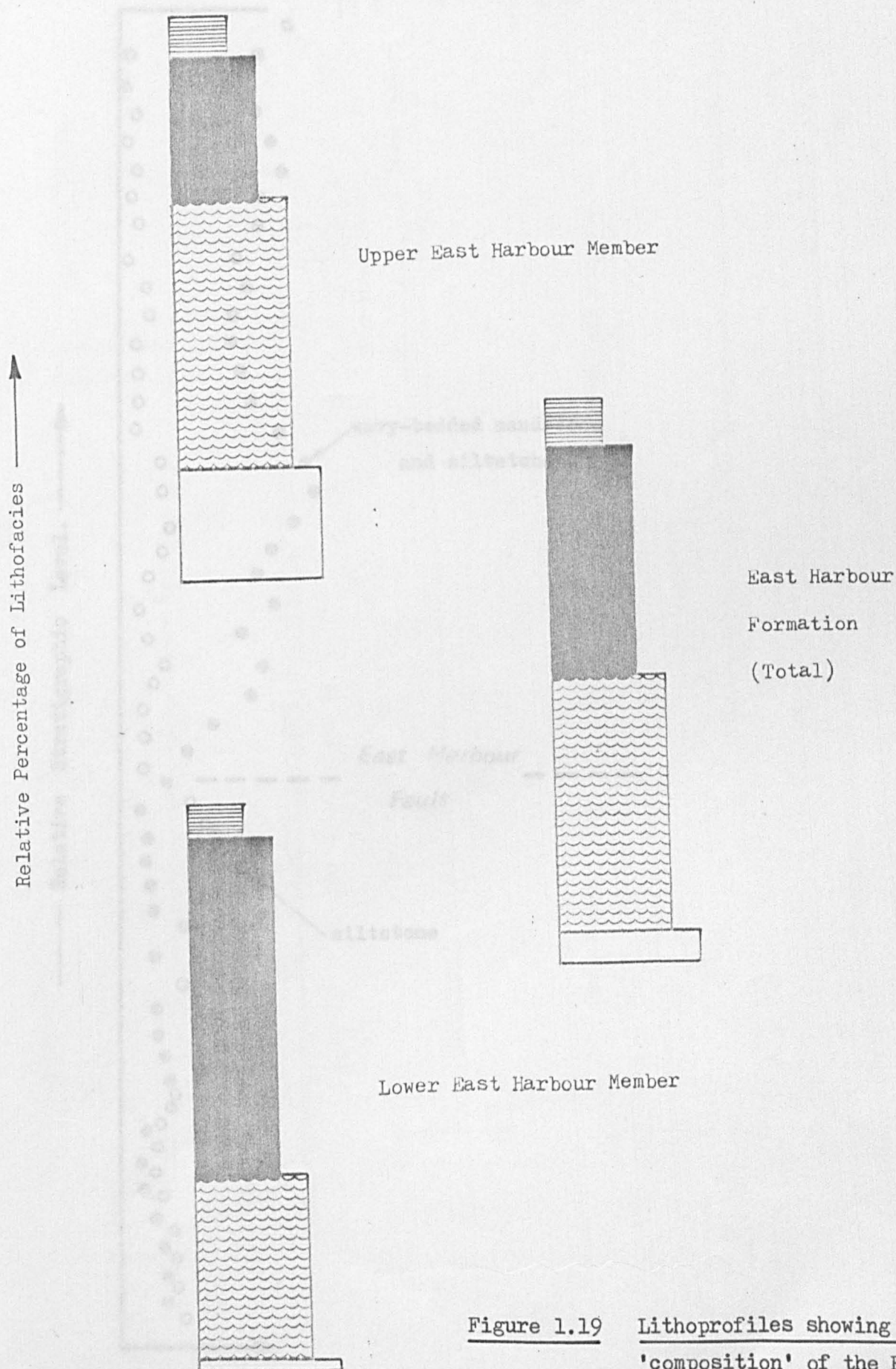
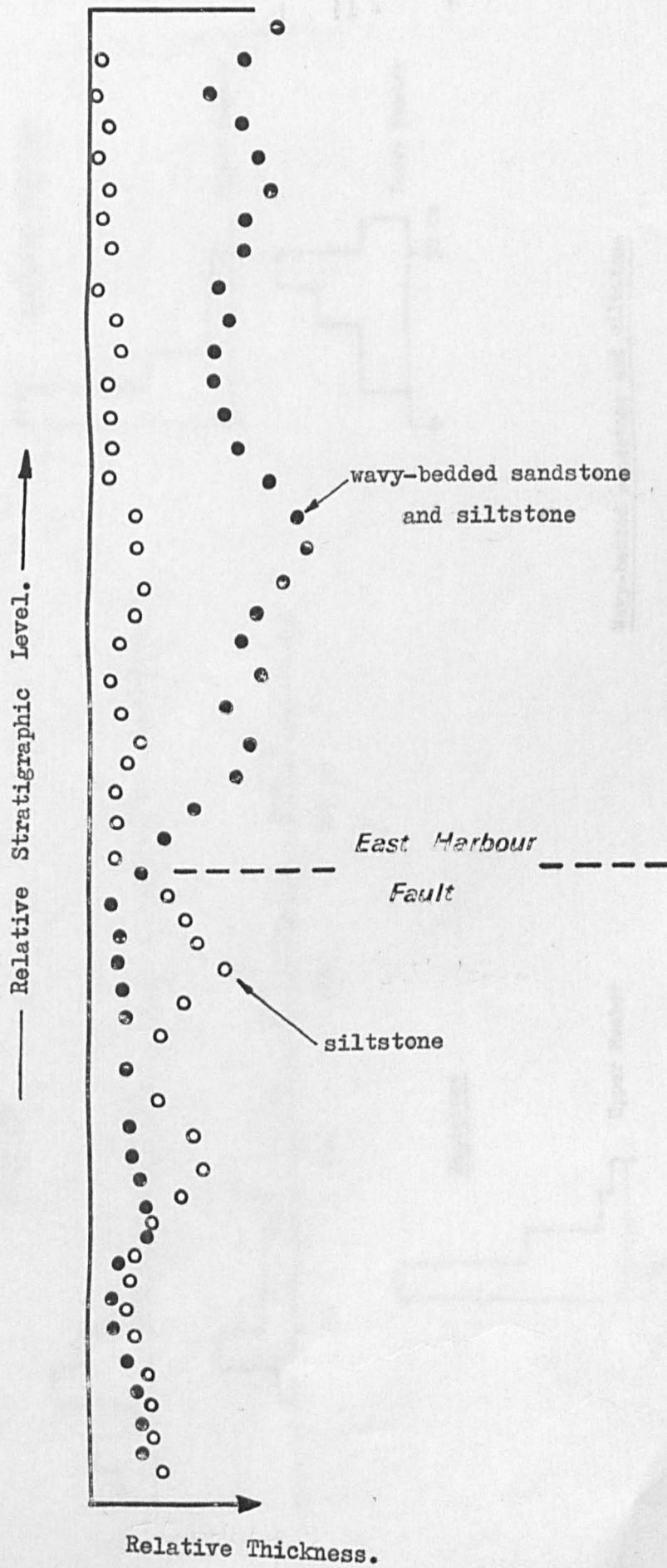


Figure 1.19 Lithoprofiles showing the
 'composition' of the East
 Harbour Formation.

Figure 1.20 'Smoothed' time trend of major lithofacies in the East Harbour Formation.



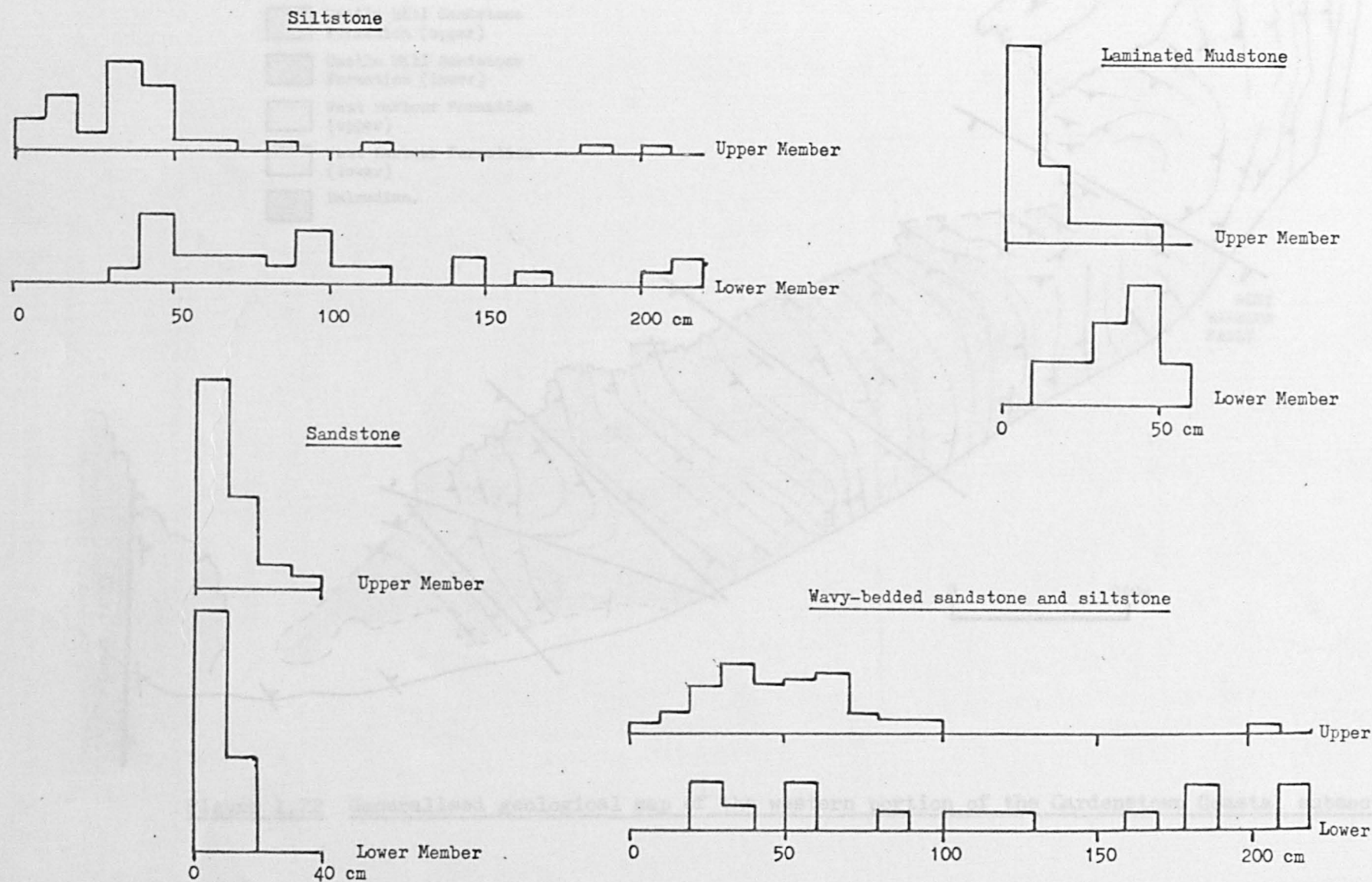


Figure 1.21 Summary of bed thickness data for the East Harbour Formation.

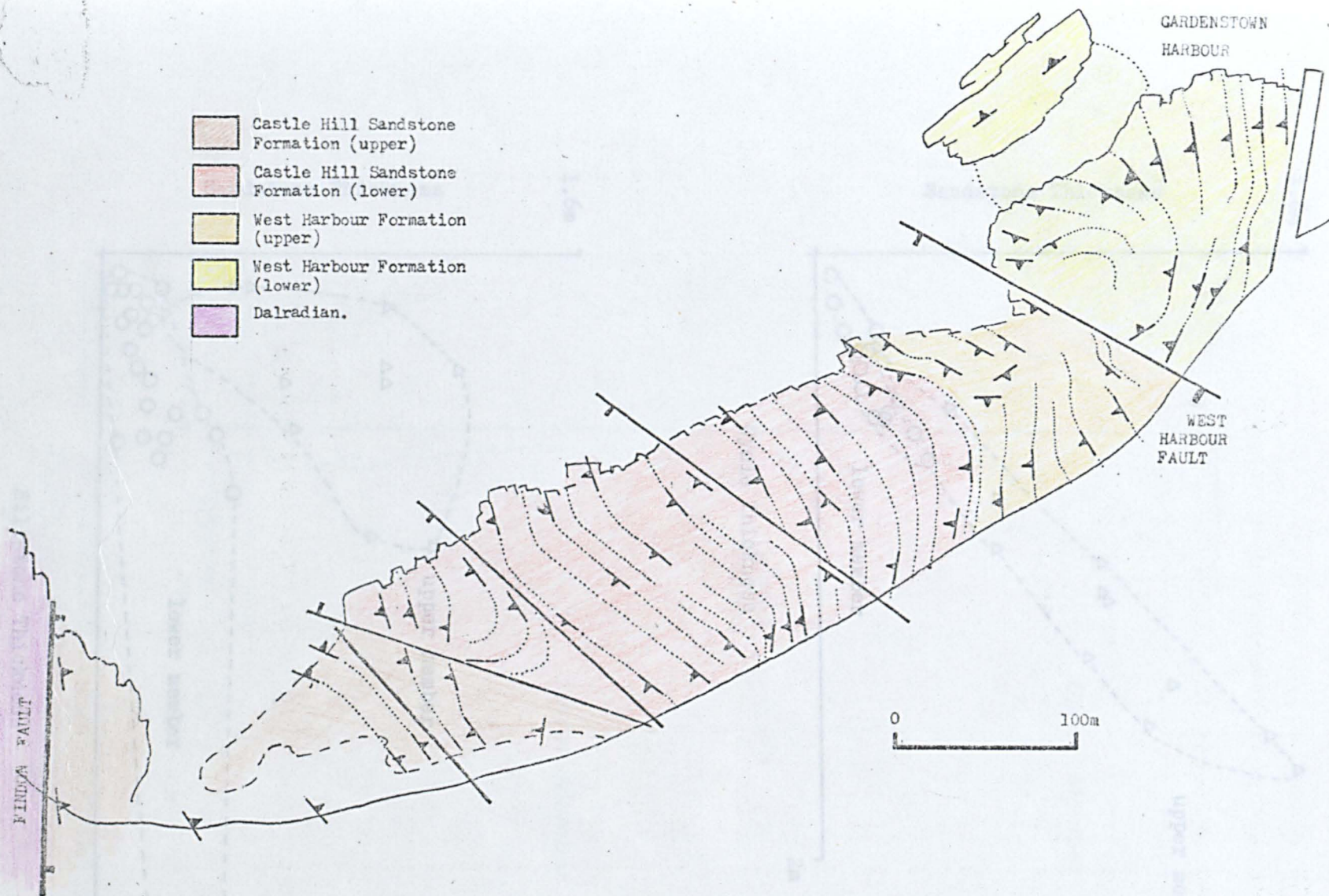


Figure 1.22 Generalised geological map of the western portion of the Gardenstown Coastal subsection.

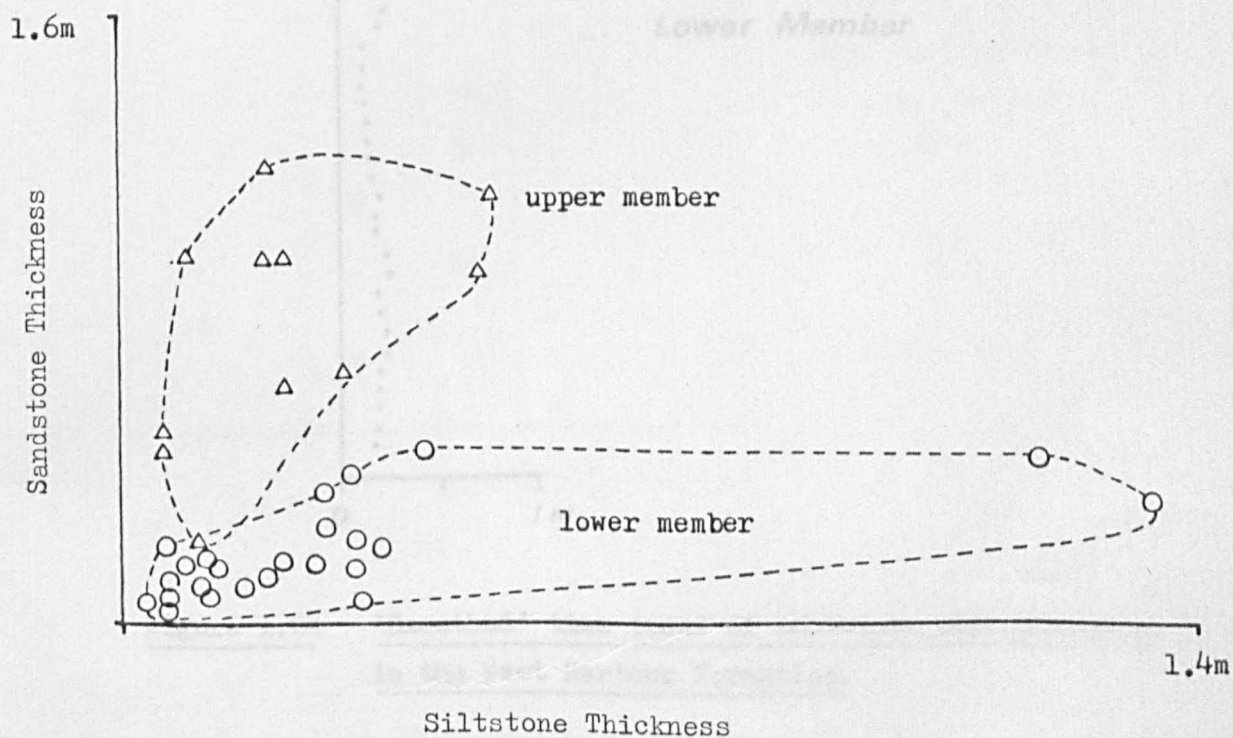
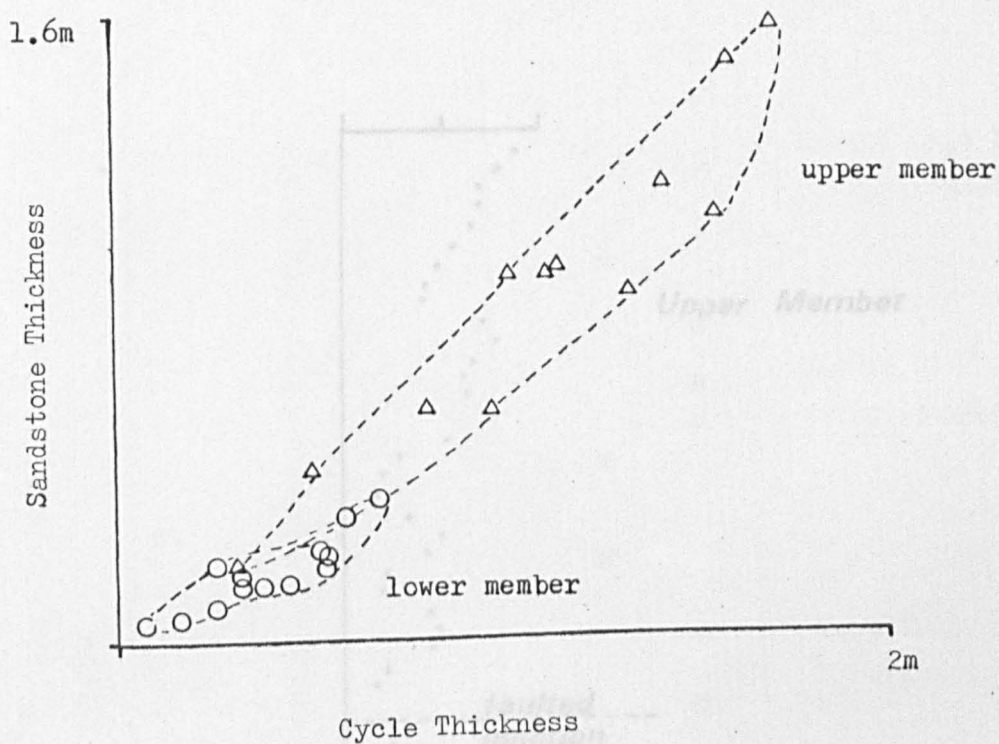


Figure 1.23 Relationships between coarse and fine portions of cycles within the West Harbour Formation.

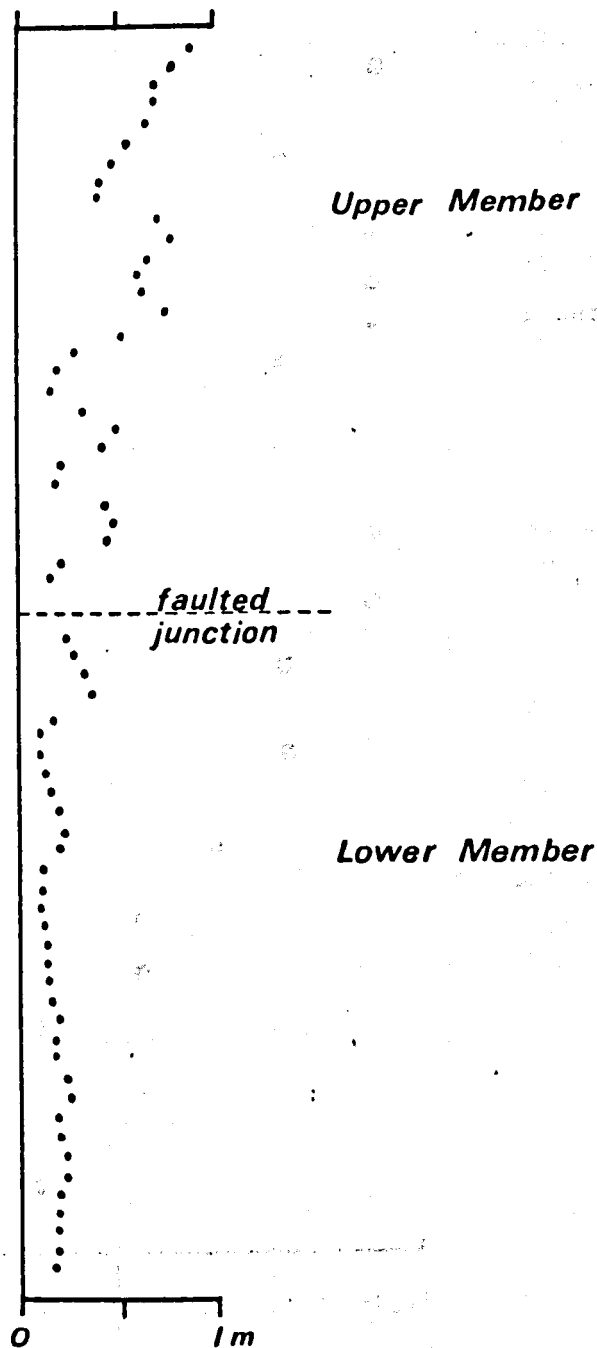


Figure 1.24 **'Smoothed' time trend of sandstone unit thickness**
in the West Harbour Formation.

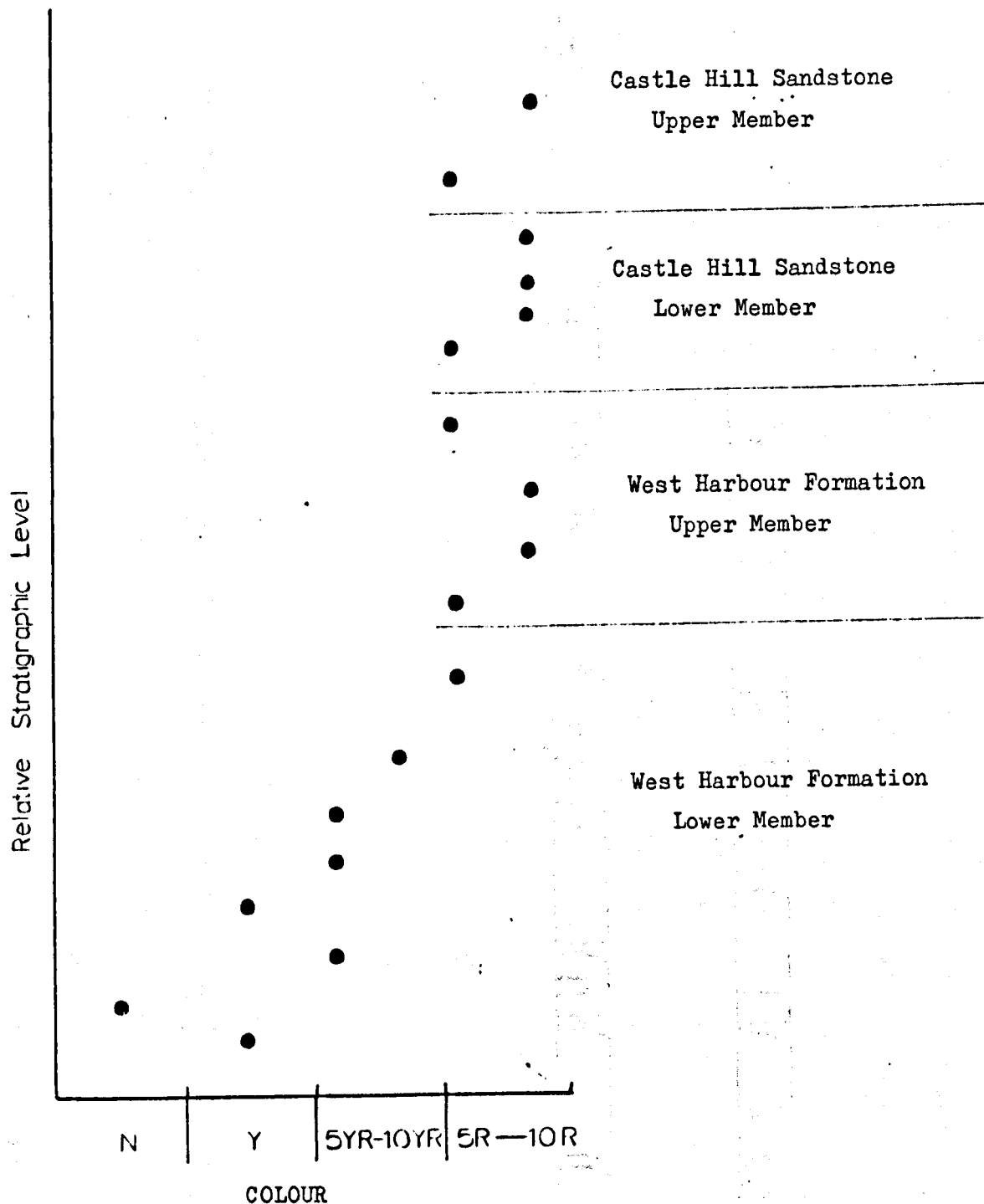


Figure 1.25 Illustration of the increasing redness of sandstone units in the West Harbour and Castle Hill Sandstone Fmns. Colour values are average for relative stratigraphic level.

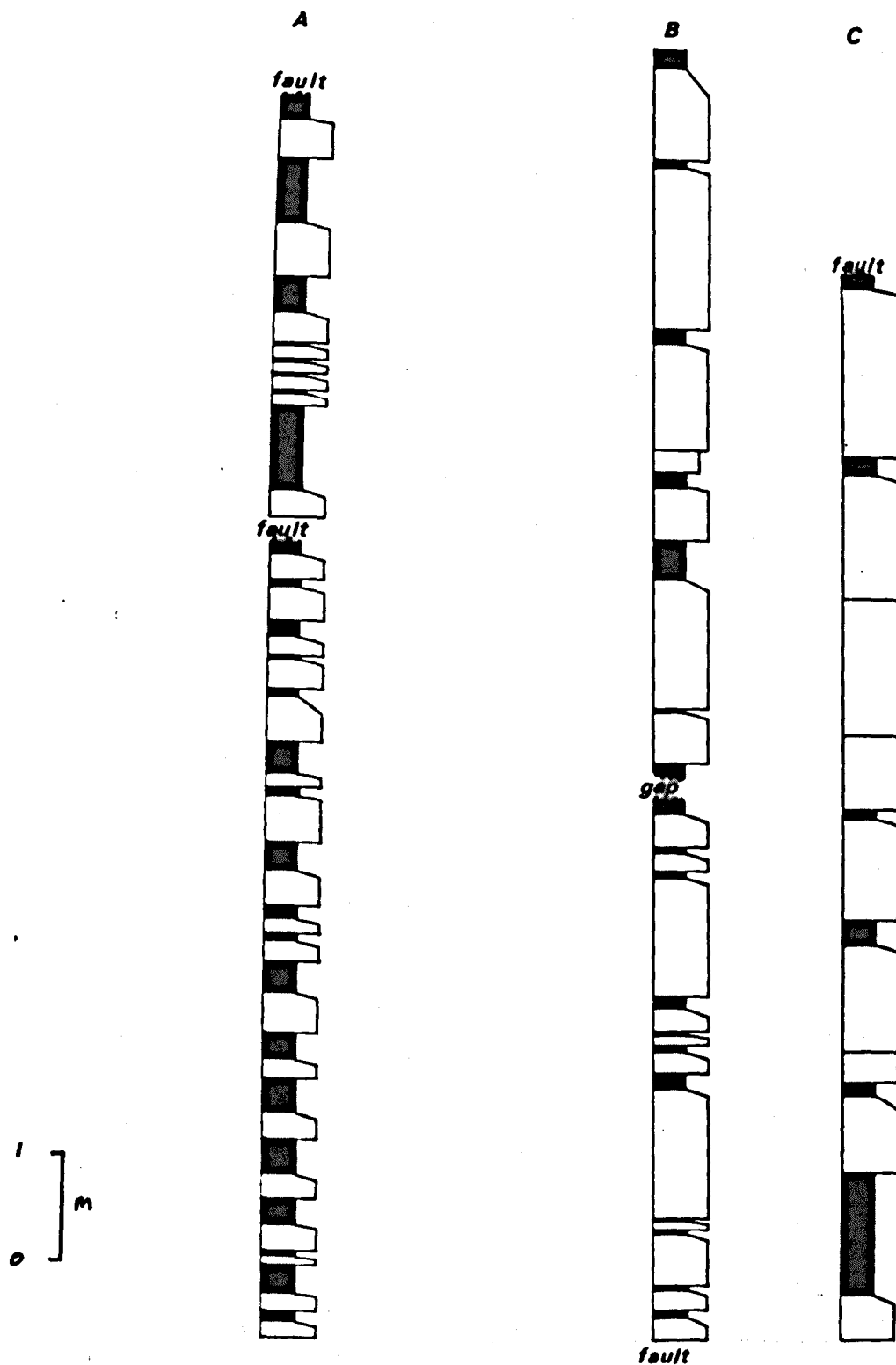


Figure 1.26 Selected field logs through the West Harbour Formation showing the distribution of 'coarse' and 'fine' units.

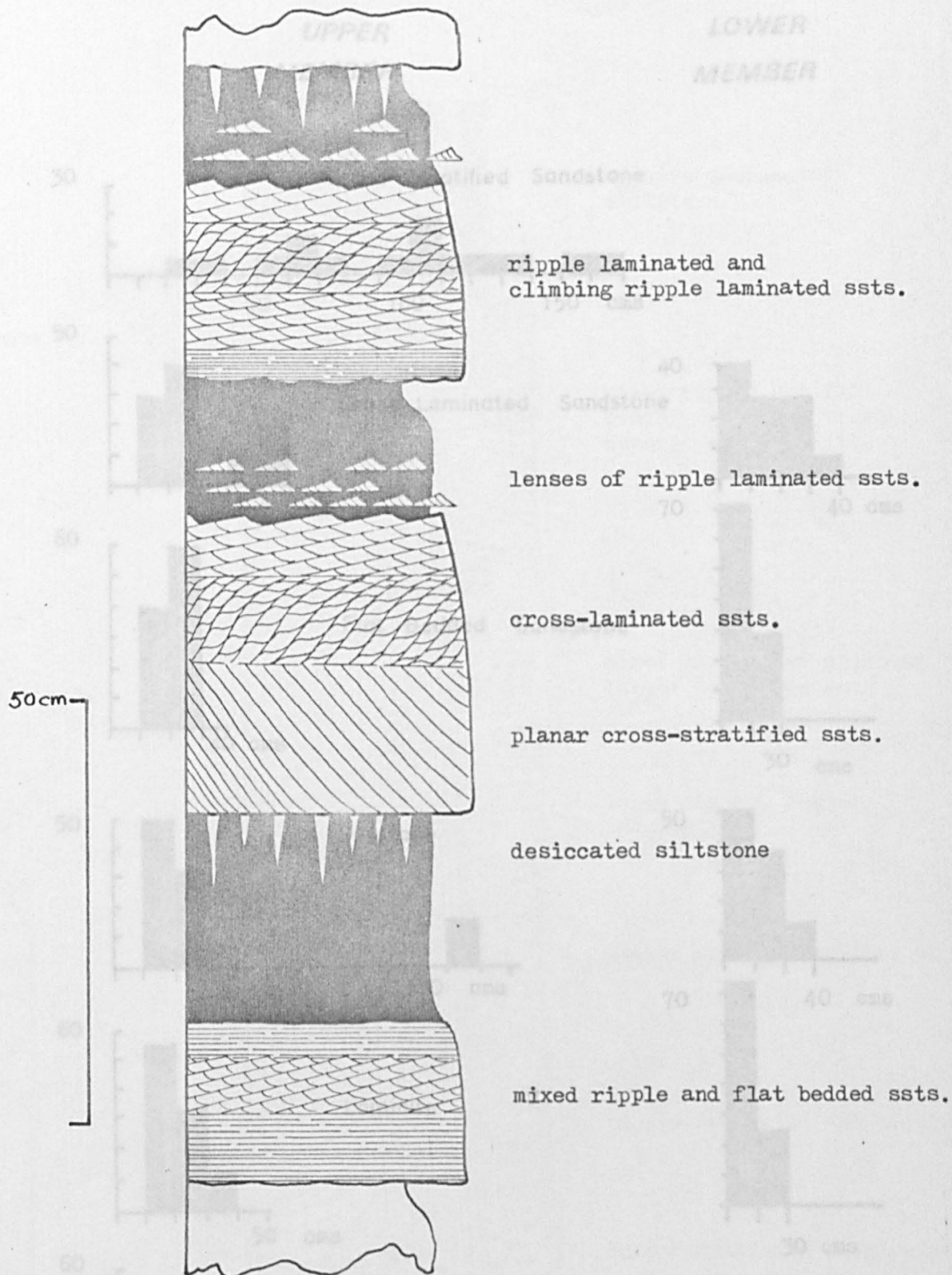
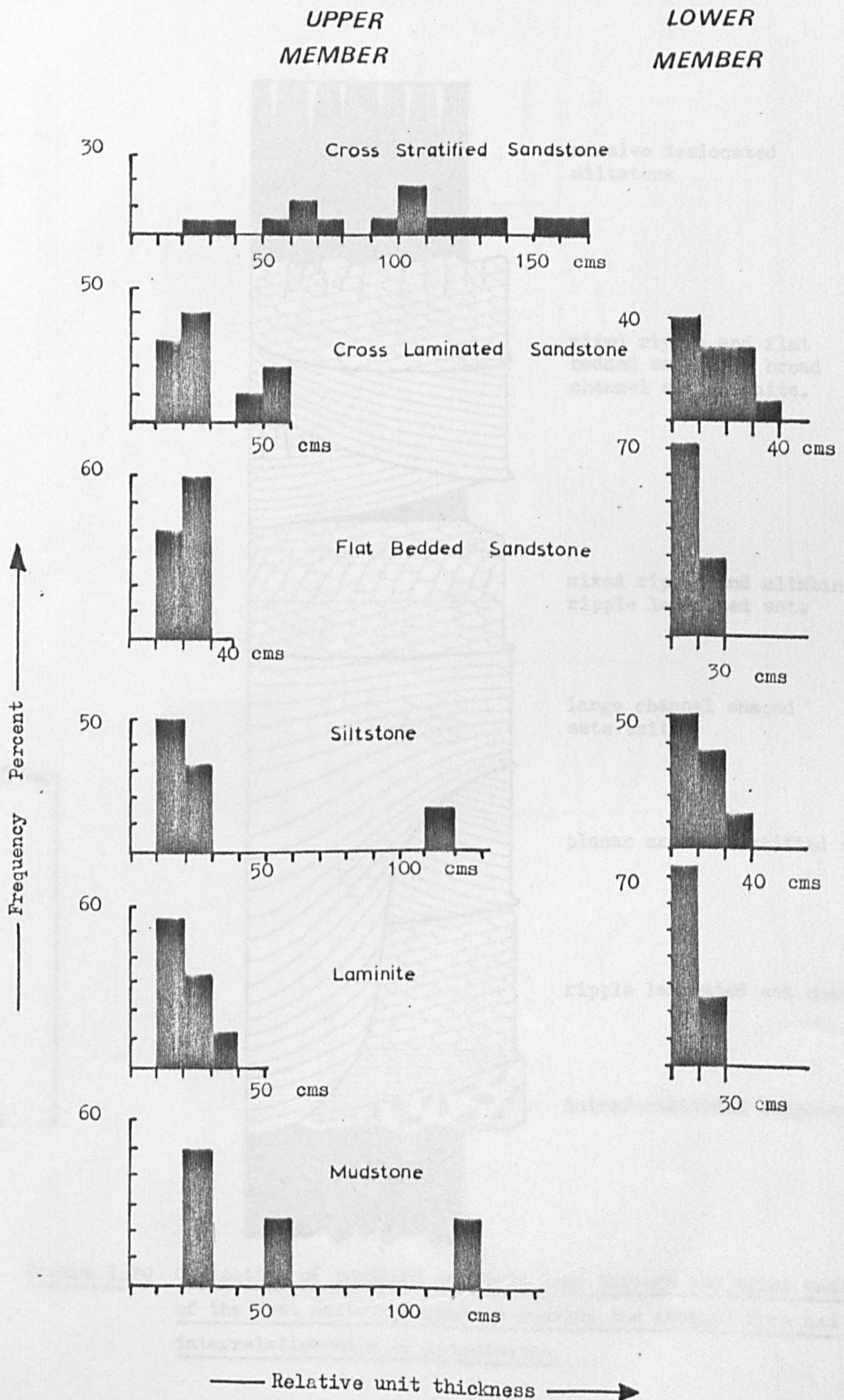


Figure 1.27 A collection of portions of field logs used to demonstrate the general form and interrelationships of lithofacies within the lower member of the West Harbour Formation.

Figure 1.28 Summary of bed thickness data for the West Harbour Formation.



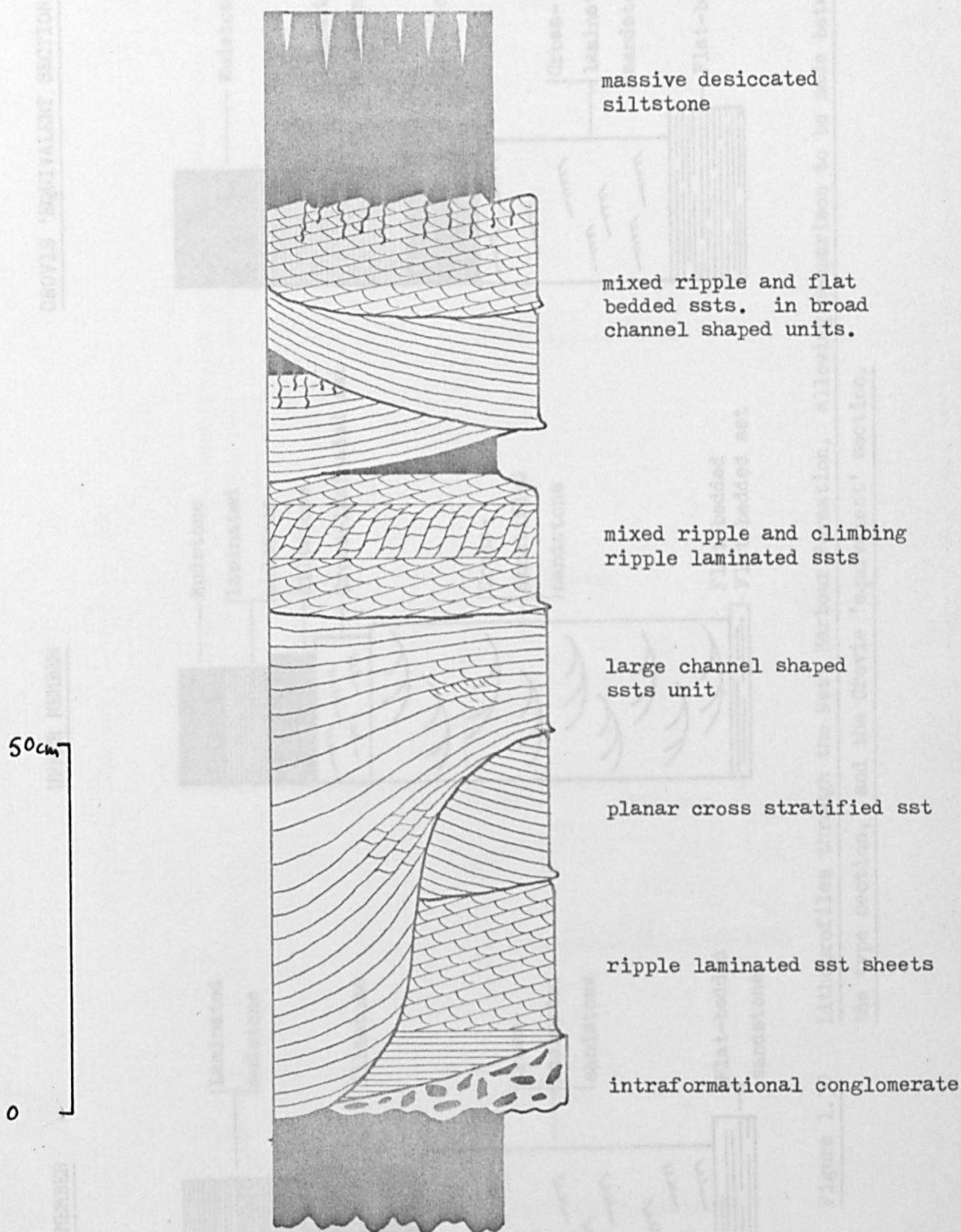


Figure 1.29 Collection of portions of field logs through the upper member of the West Harbour Formation showing the general form and interrelationships of lithofacies.

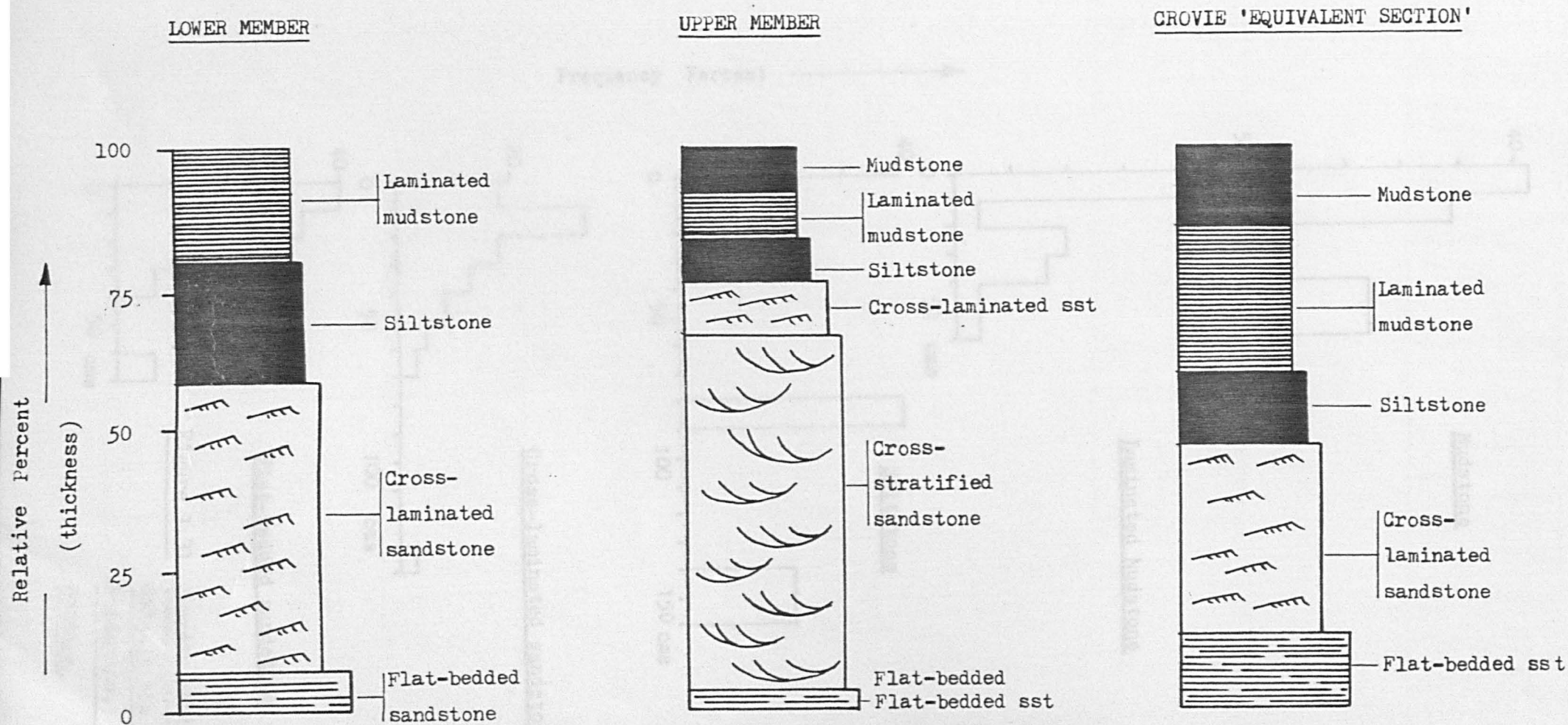


Figure 1.30 Lithoprophiles through the West Harbour Formation, allowing comparison to be made between the type section, and the Crovie 'equivalent' section.

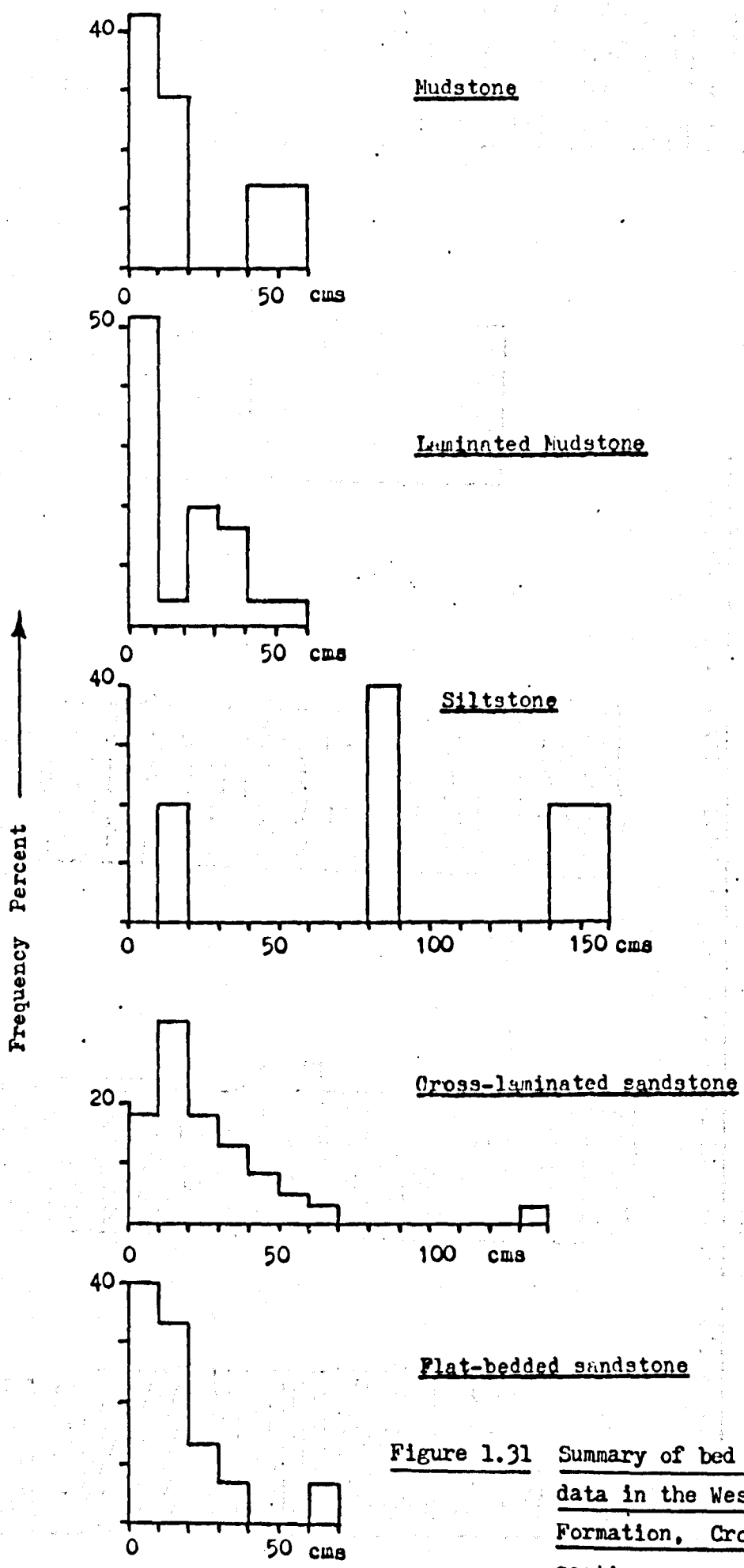
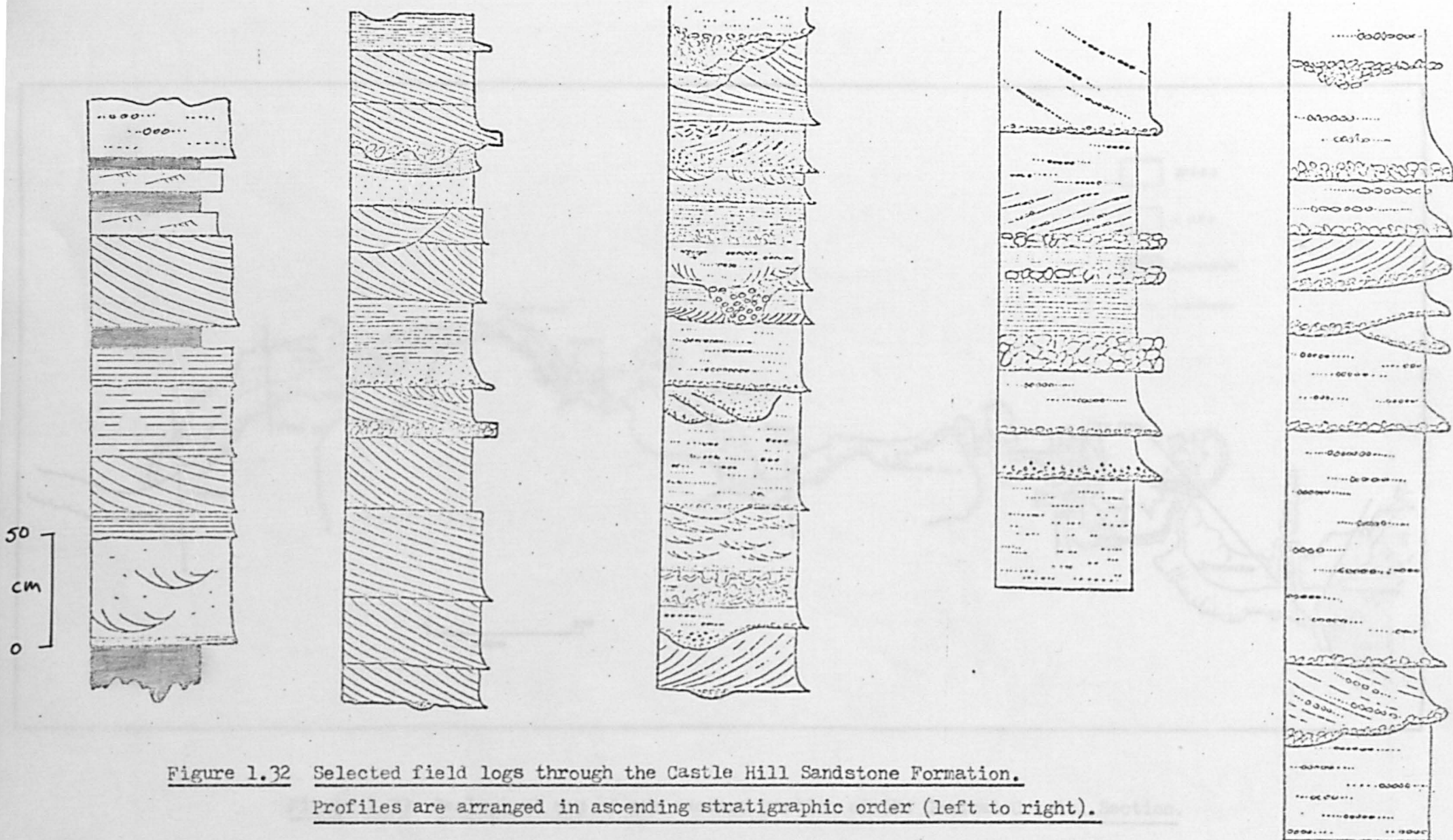


Figure 1.31 Summary of bed thickness data in the West Harbour Formation, Crovie equivalent section.



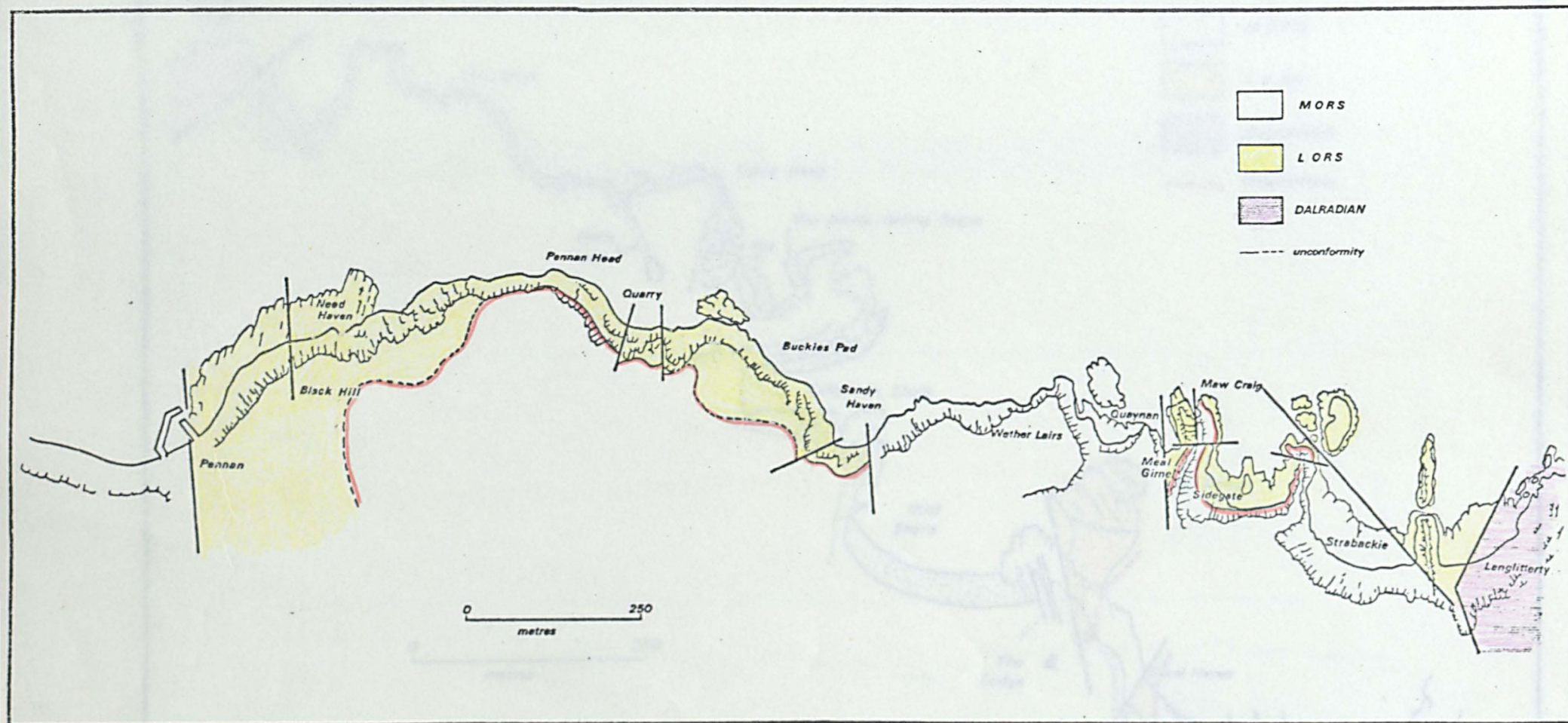


Figure 1.33 Geological map of the eastern portion of the Central Coastal Section.

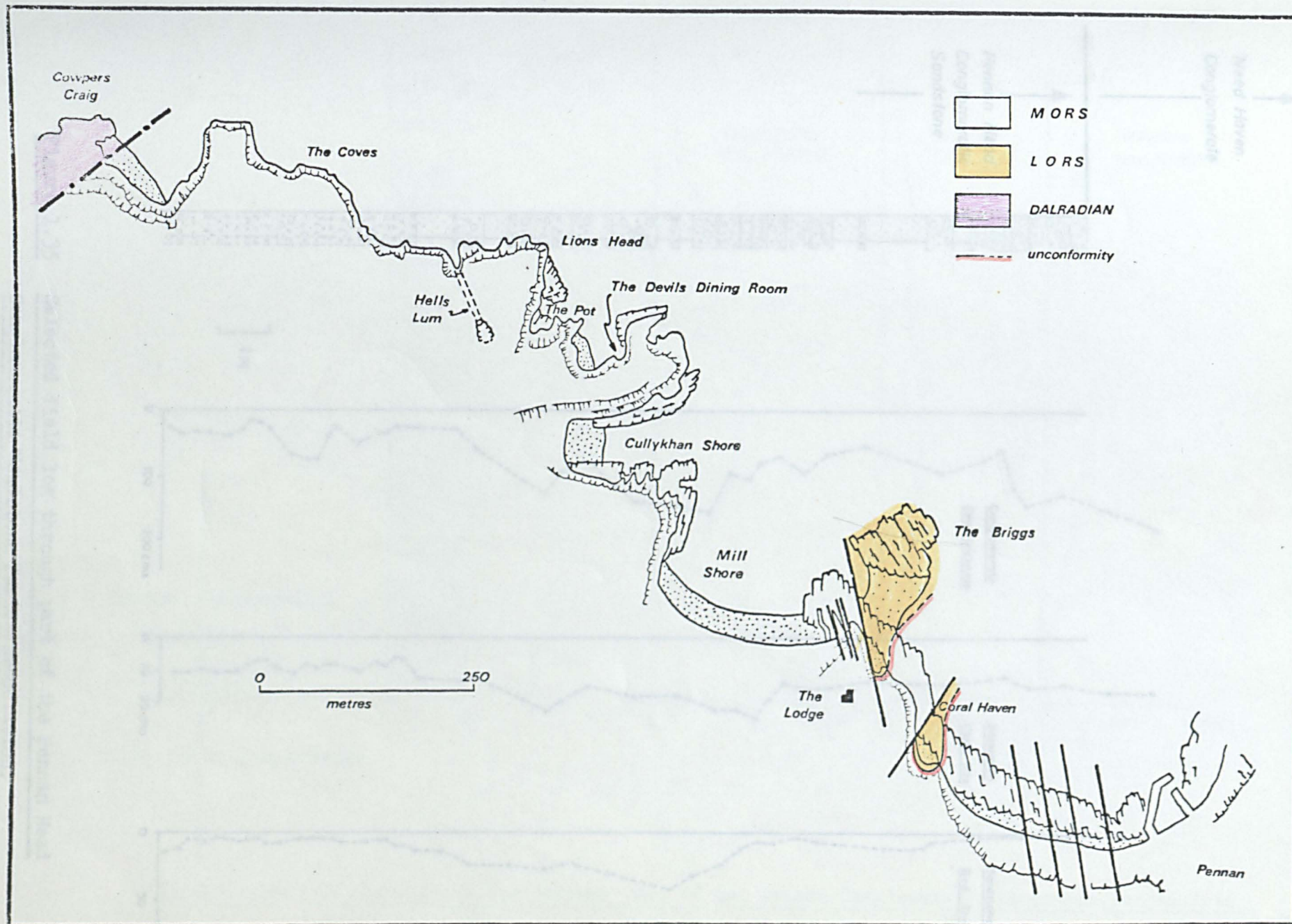


Figure 1.34 Geological map of the western portion of the Central Coastal Section.

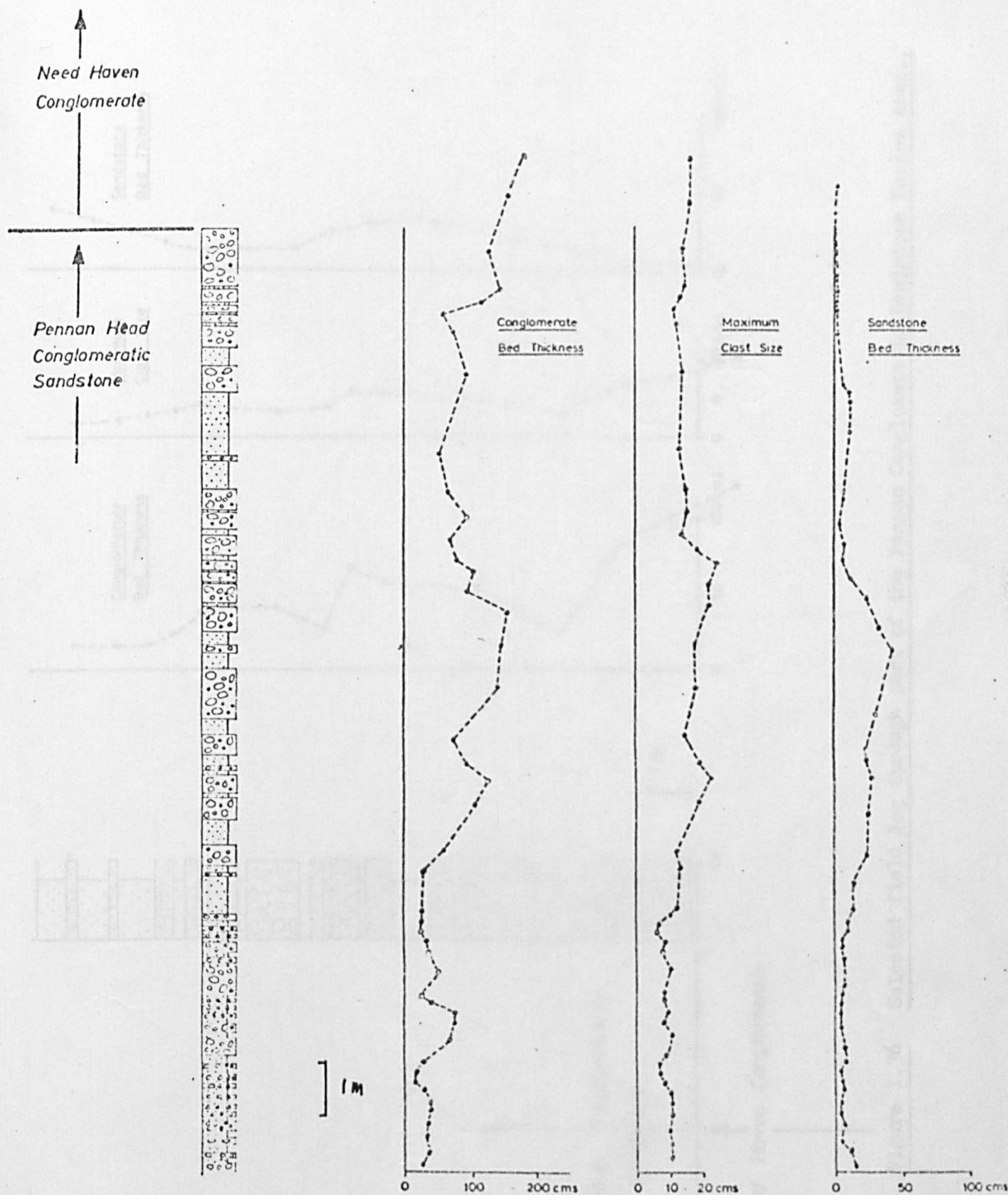


Figure 1.35 Selected field log through part of the Pennan Head
Conglomeratic Sandstone Facies Association.

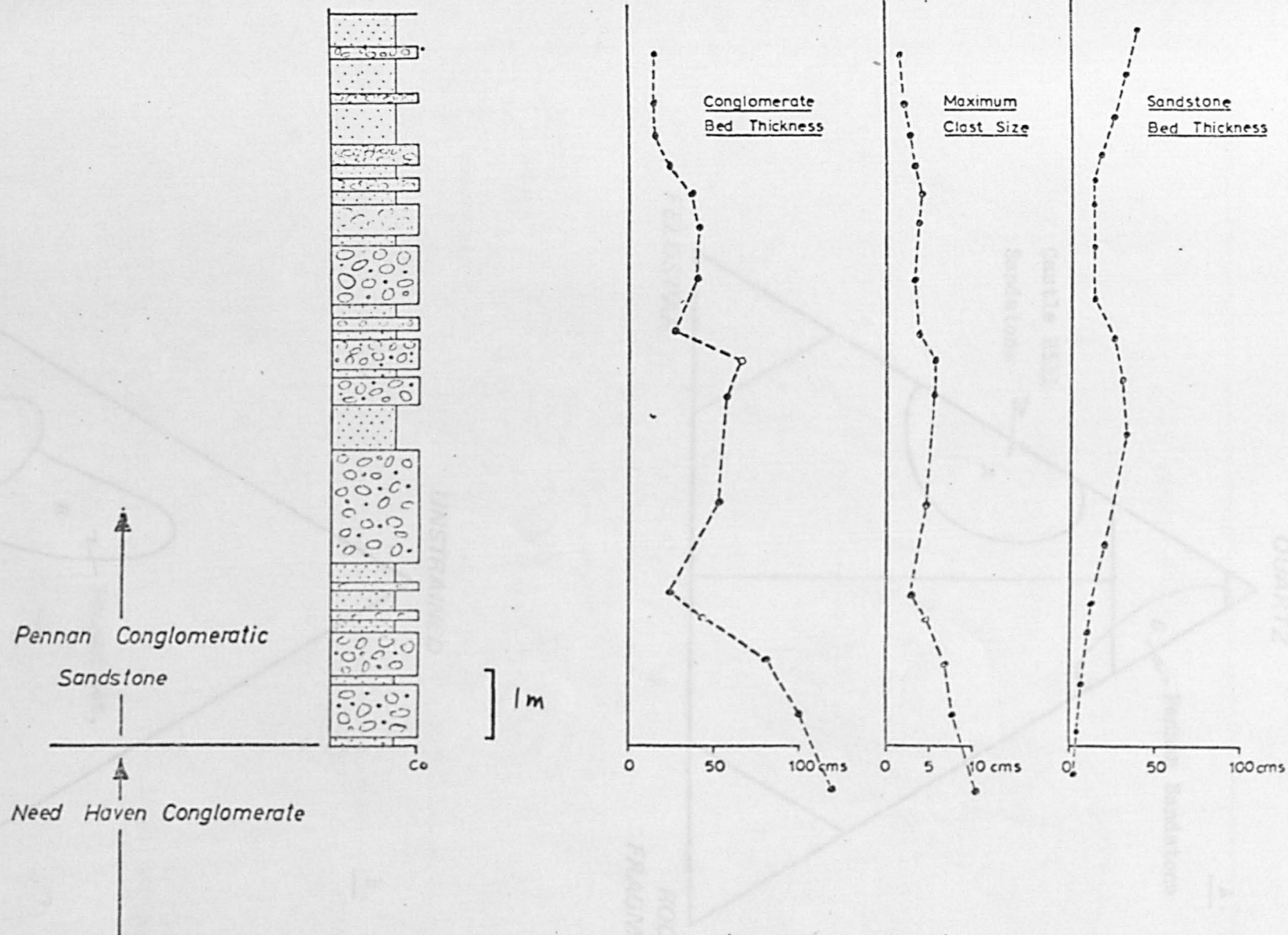
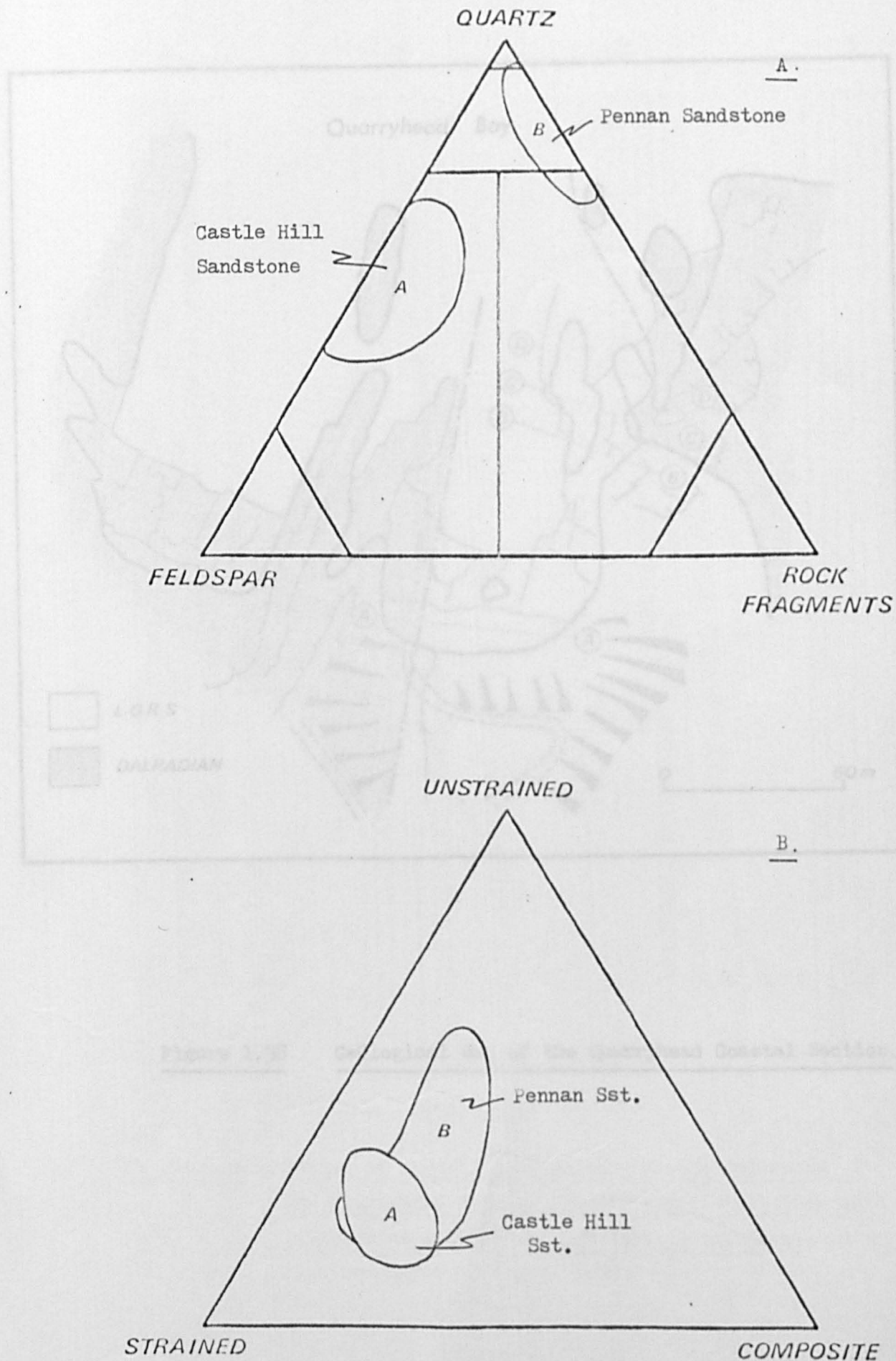


Figure 1.36 Selected field log through part of the Pennan Conglomeratic Sandstone Facies Assn..

Figure 1.37 Comparison of sandstone composition between the Pennan Sandstone and Castle Hill Sst Fmn..



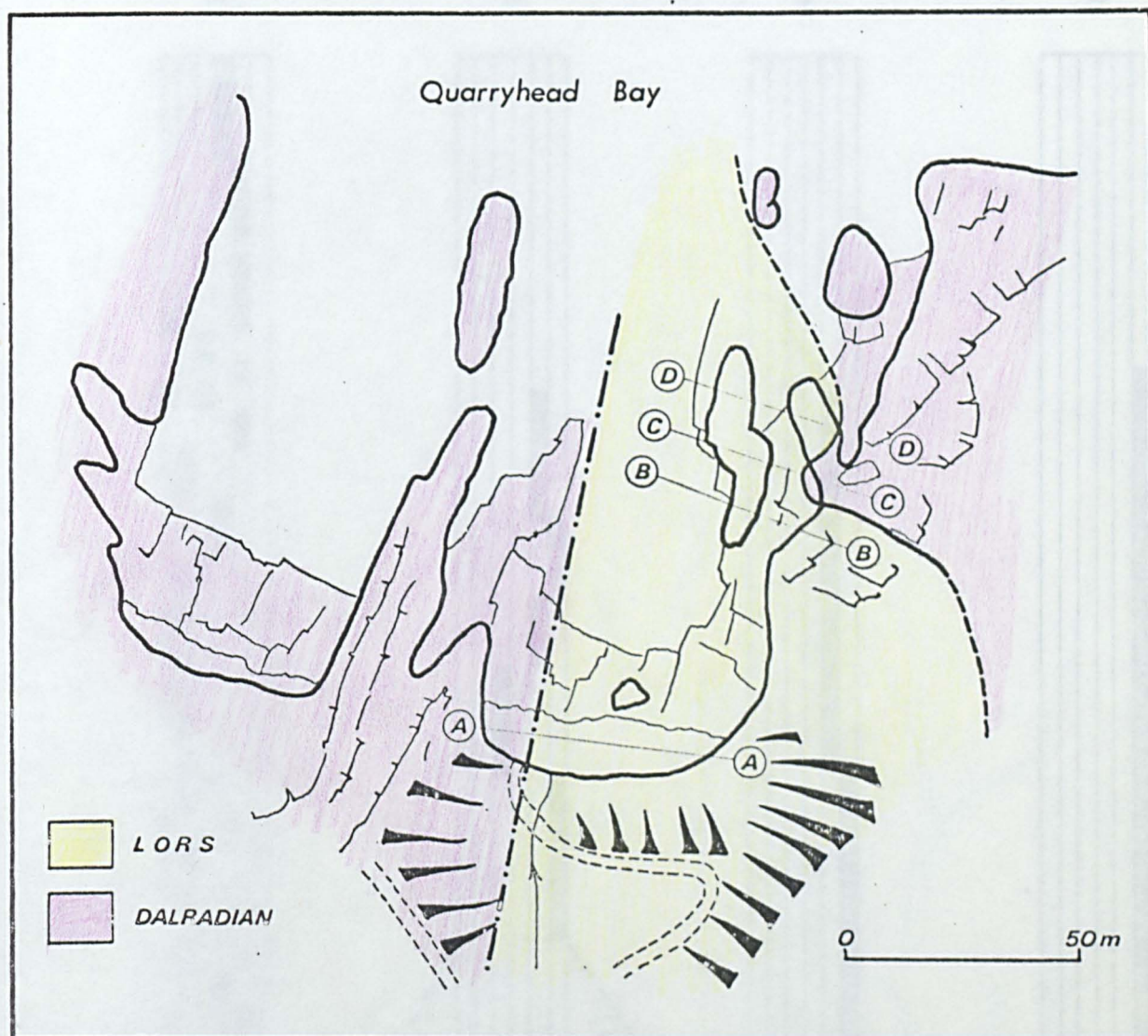


Figure 1.38

Geological map of the Quarryhead Coastal Section.

Line of section (letters refer to fig.1.38)

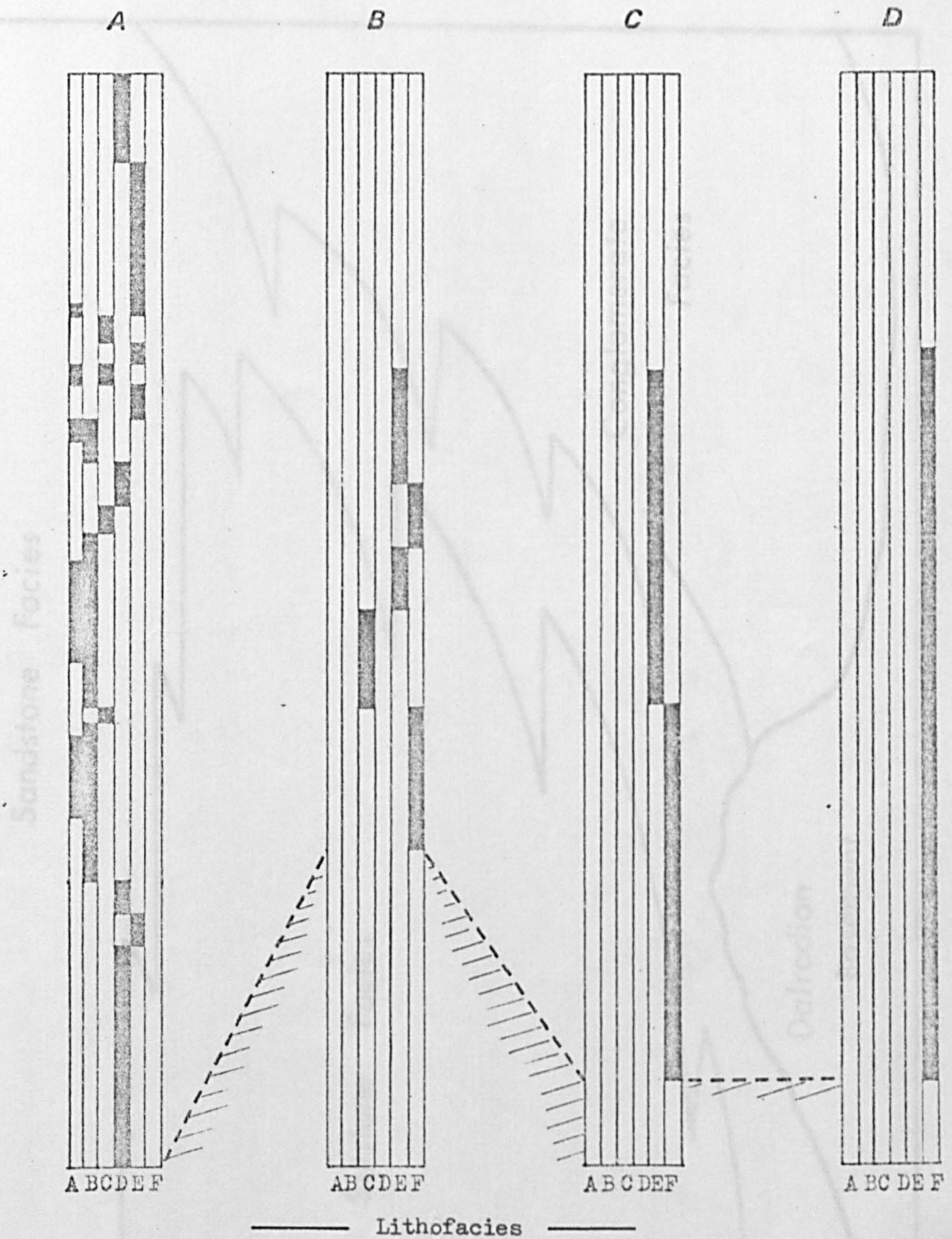


Figure 1.39

Series of logged profiles through the sediments of the Quarryhead Outlier showing the distribution of lithofacies in vertical and lateral sections.
(letters refer to figure 1.38)

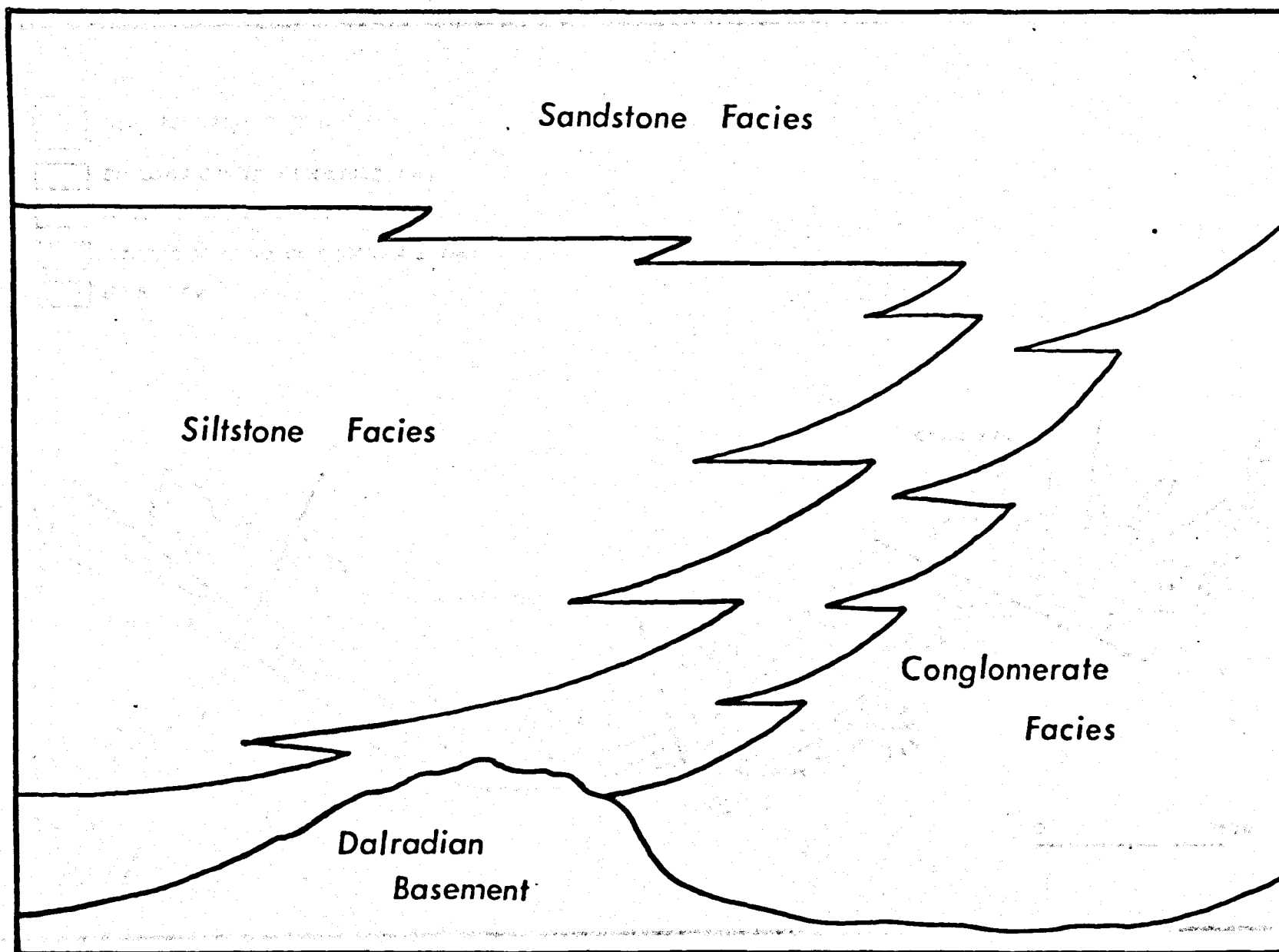


Figure 1.40 Schematic diagram of possible facies relationships at Quarryhead.

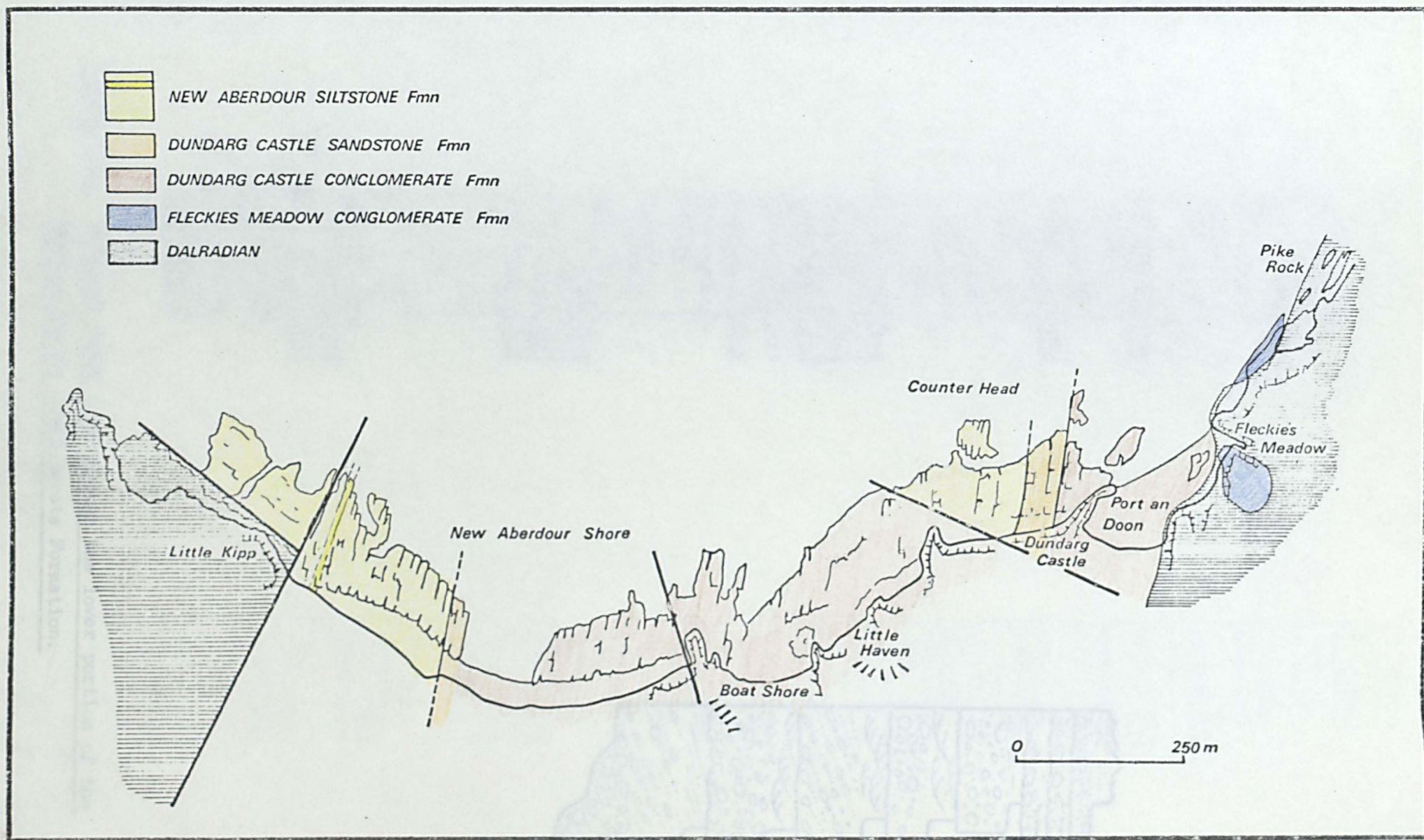


Figure 1.41 Geological map of the Eastern Coastal Section.

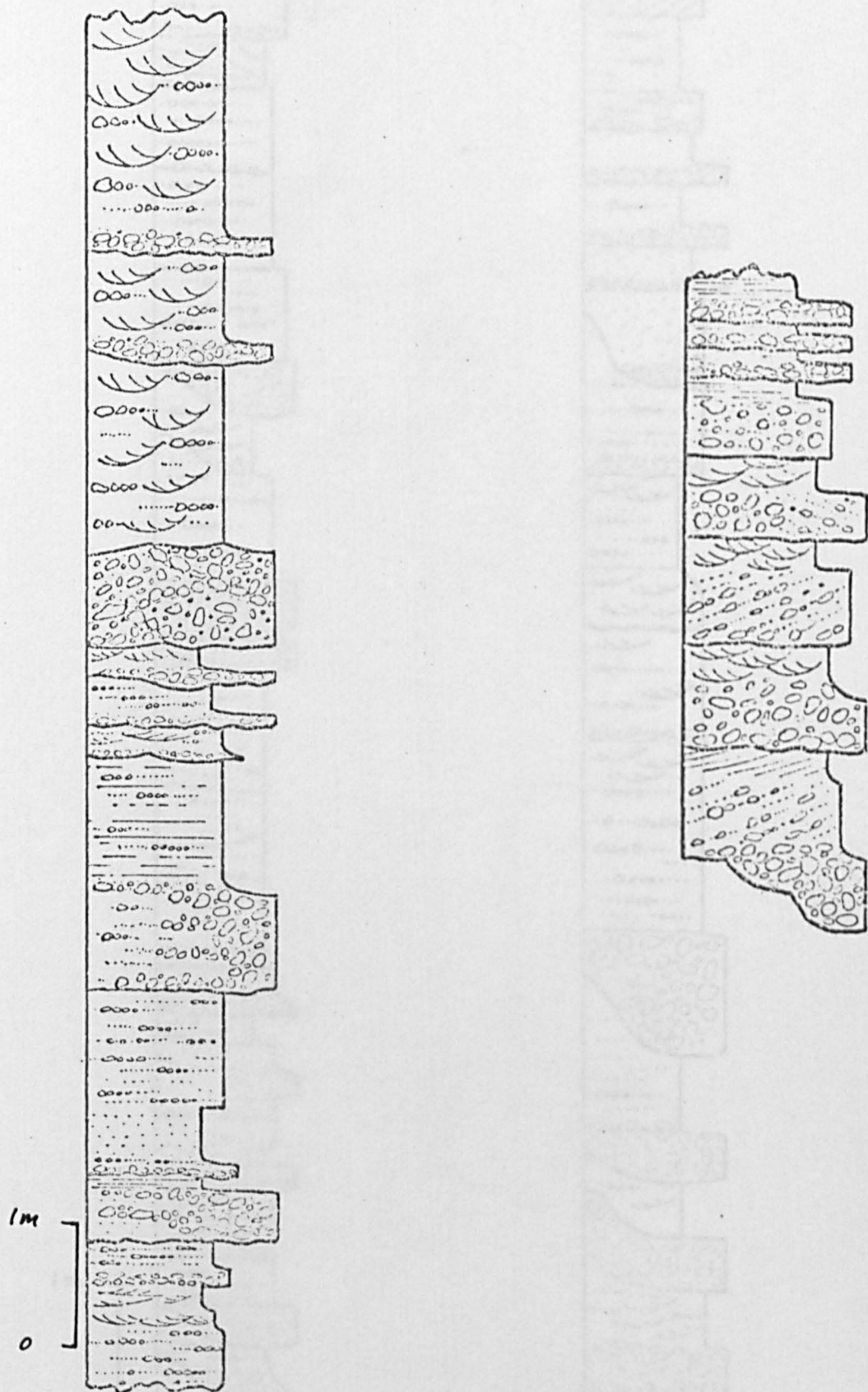


Figure 1.42 Selected field logs through the lower portion of the Dundarg Castle Conglomerate Formation.

DUNDARG CASTLE CONGLOMERATE FORMATION

1m
0

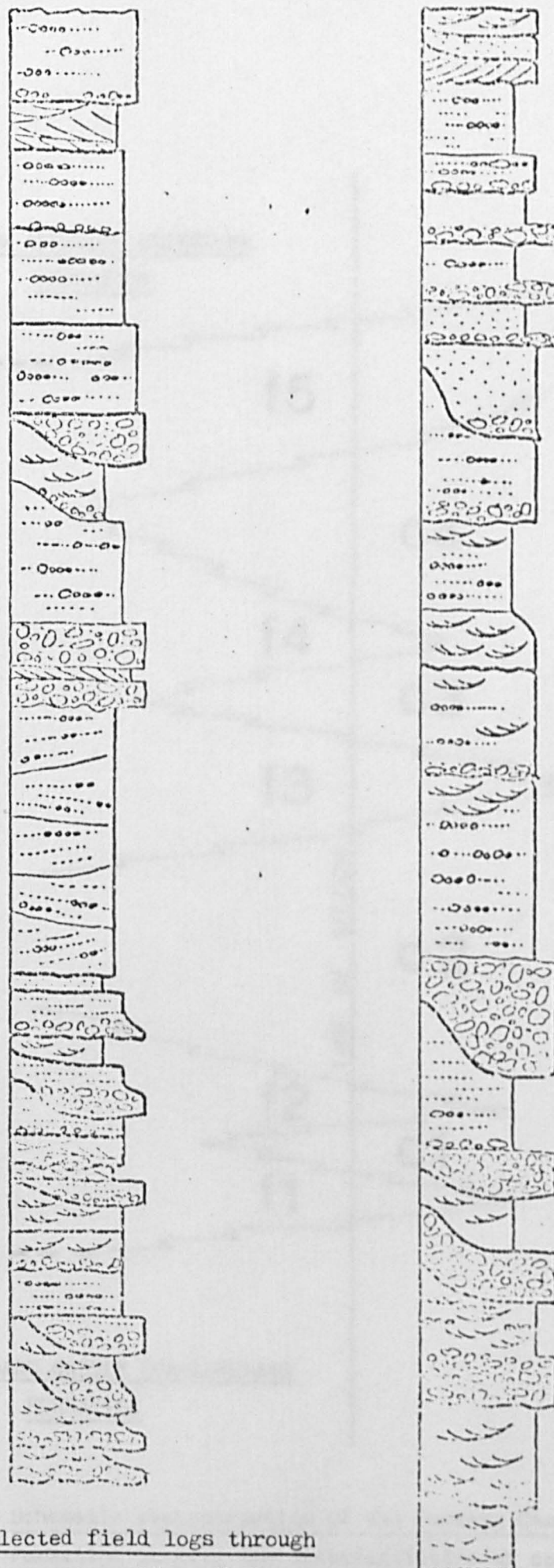


Figure 1.43 Selected field logs through the upper portion of the Dundarg Castle Conglomerate Formation.

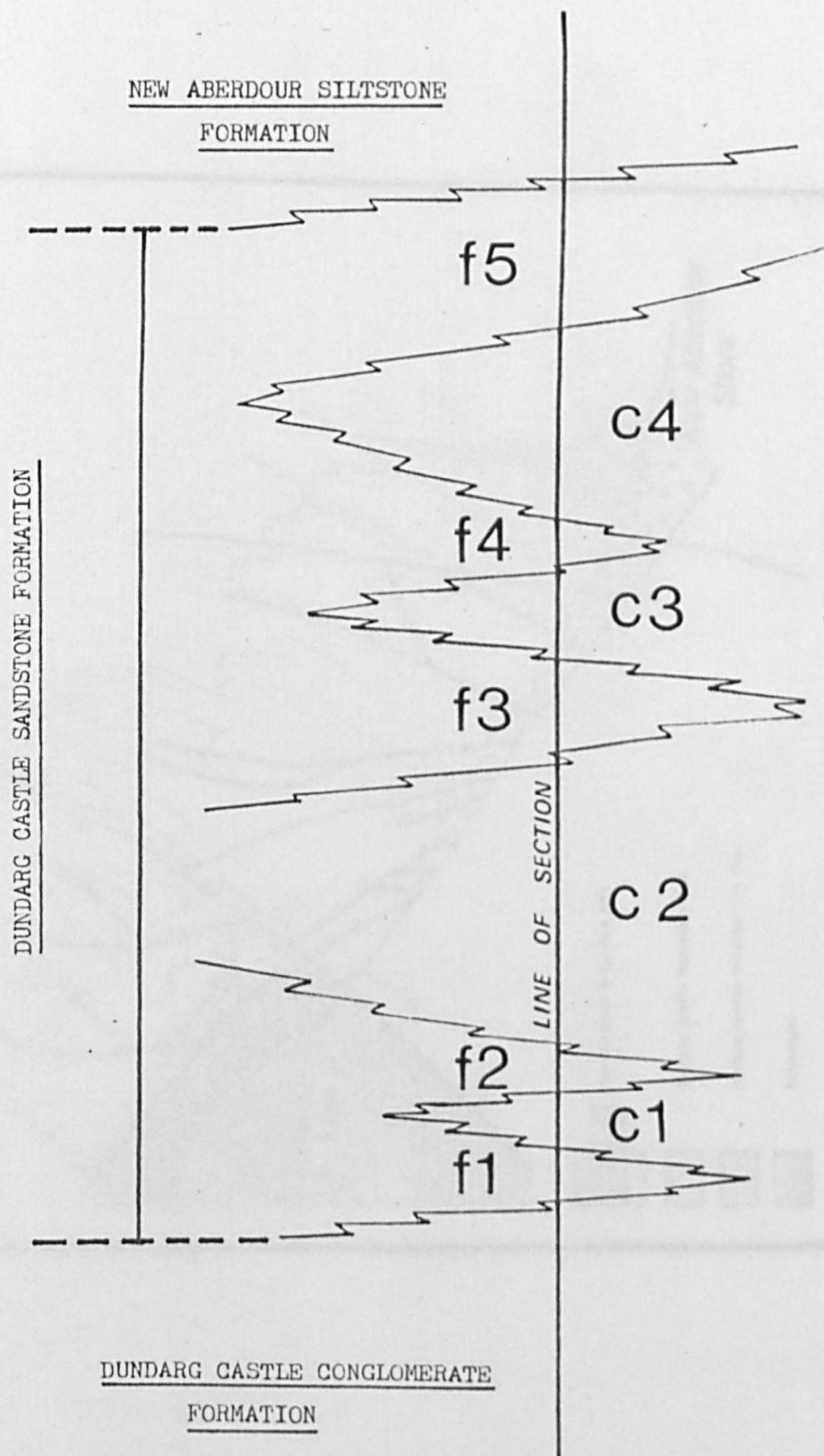


Figure 1.44 Schematic reconstruction of the Dundarg Castle Sandstone Formation showing the interdigitation of coarse and fine members.

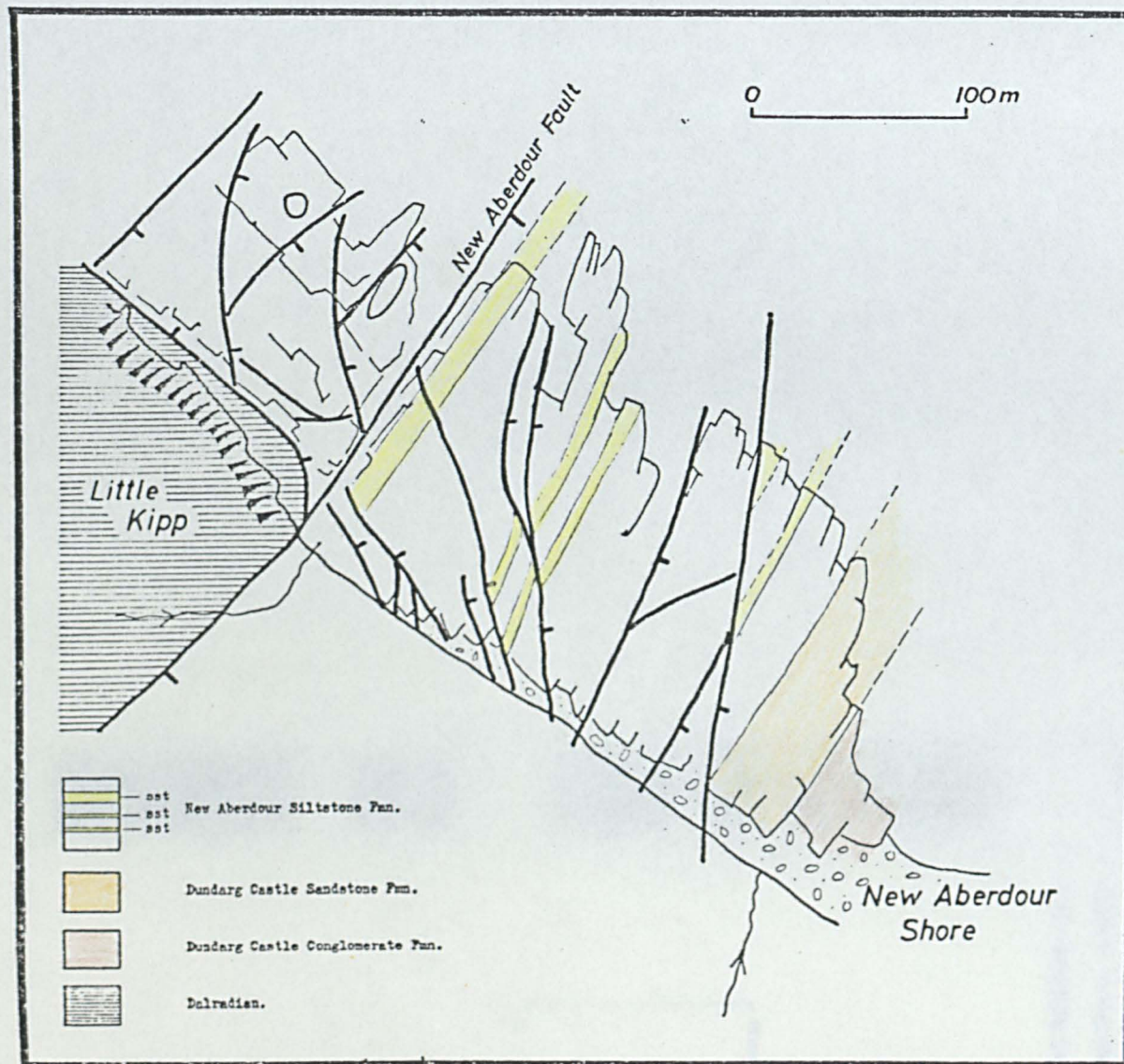


Figure 1.45 Geological map of the New Aberdour Shore Subsection.

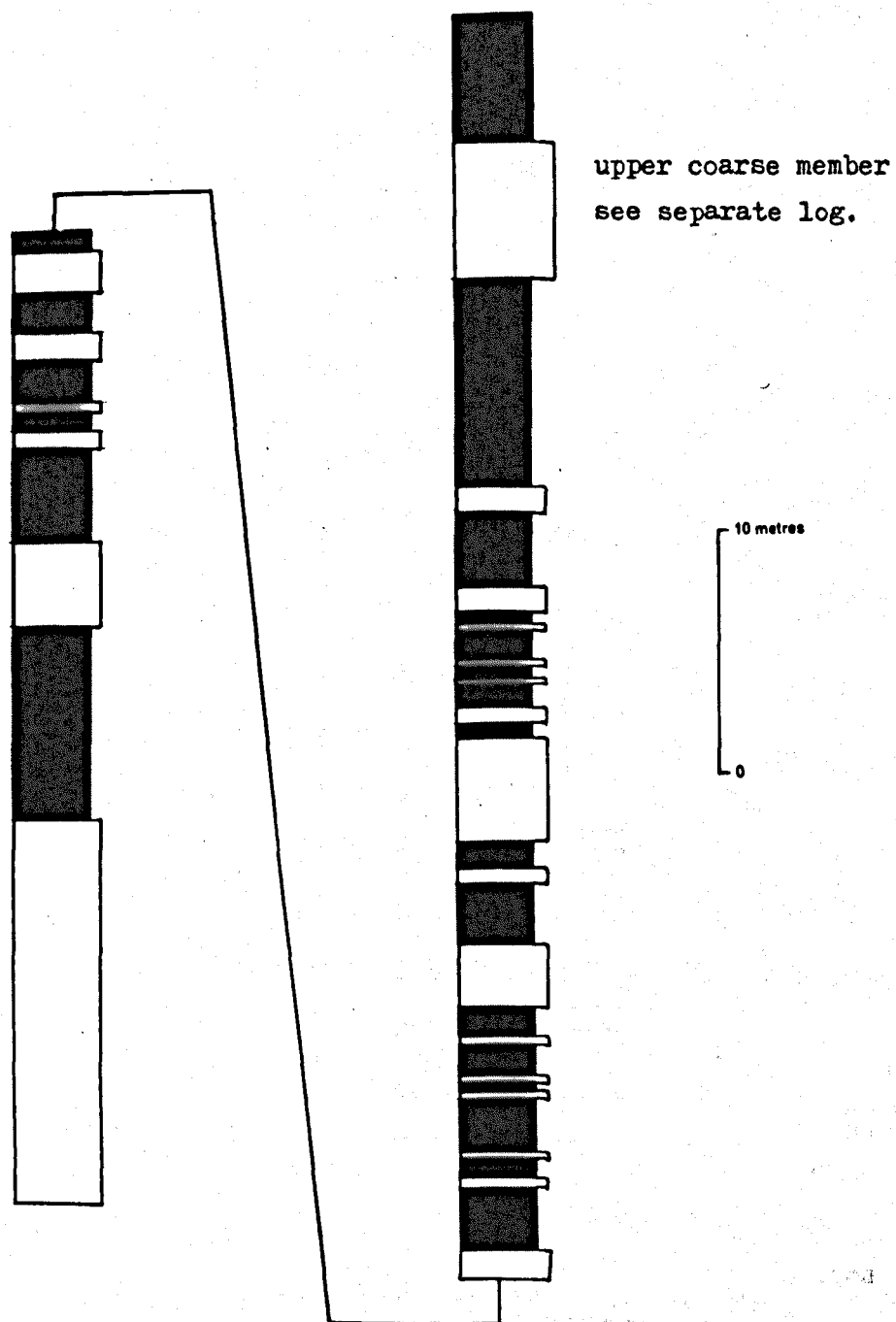


Figure 1.46 Field log through the New Aberdour Siltstone Formation.

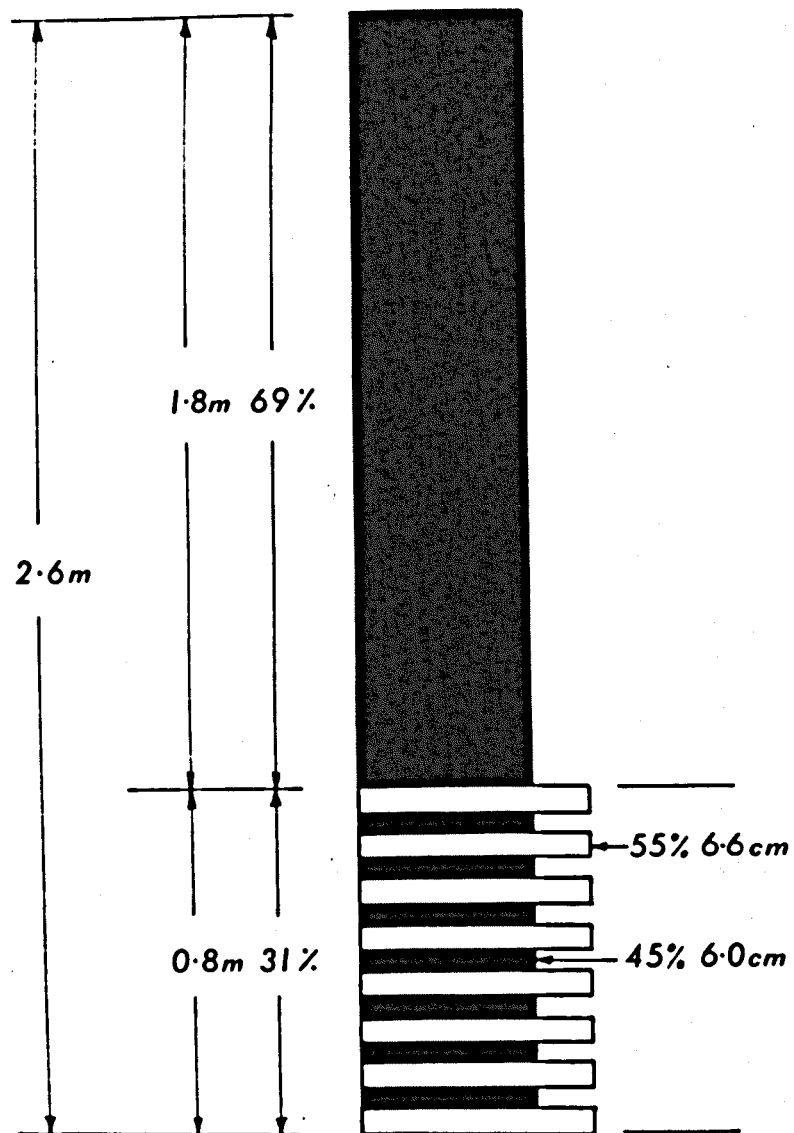


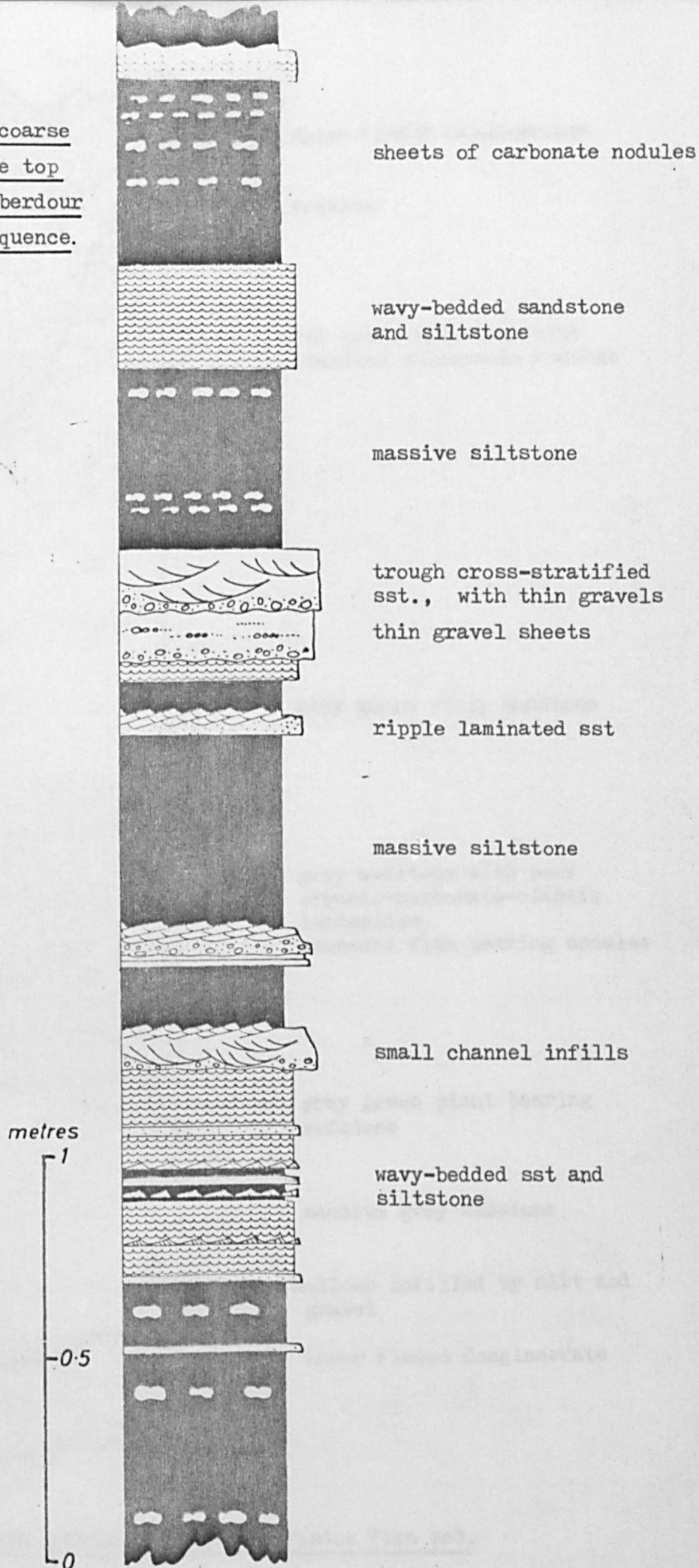
Figure 1.47

A reconstruction of the average Siltstone Formation cycle showing the composition and thickness of lithofacies.

Through the course
center at the top
of the

Figure 1.48 Detailed field log through a portion of the New Aberdour Siltstone Formation sequence demonstrating the general nature of the coarse units of cycles.

Figure 1.49 Detailed log
through the coarse
member at the top
of the New Aberdour
Siltstone sequence.



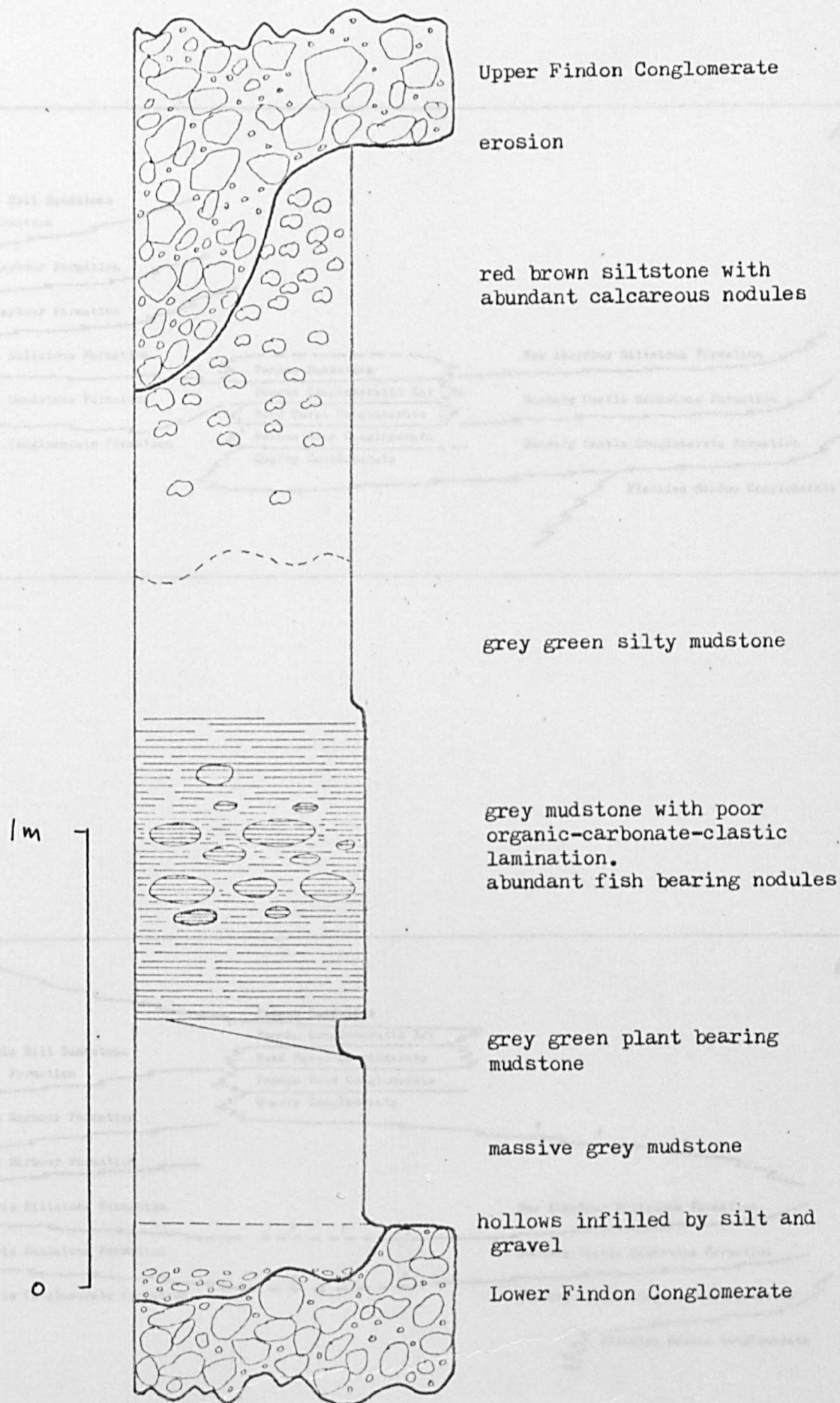
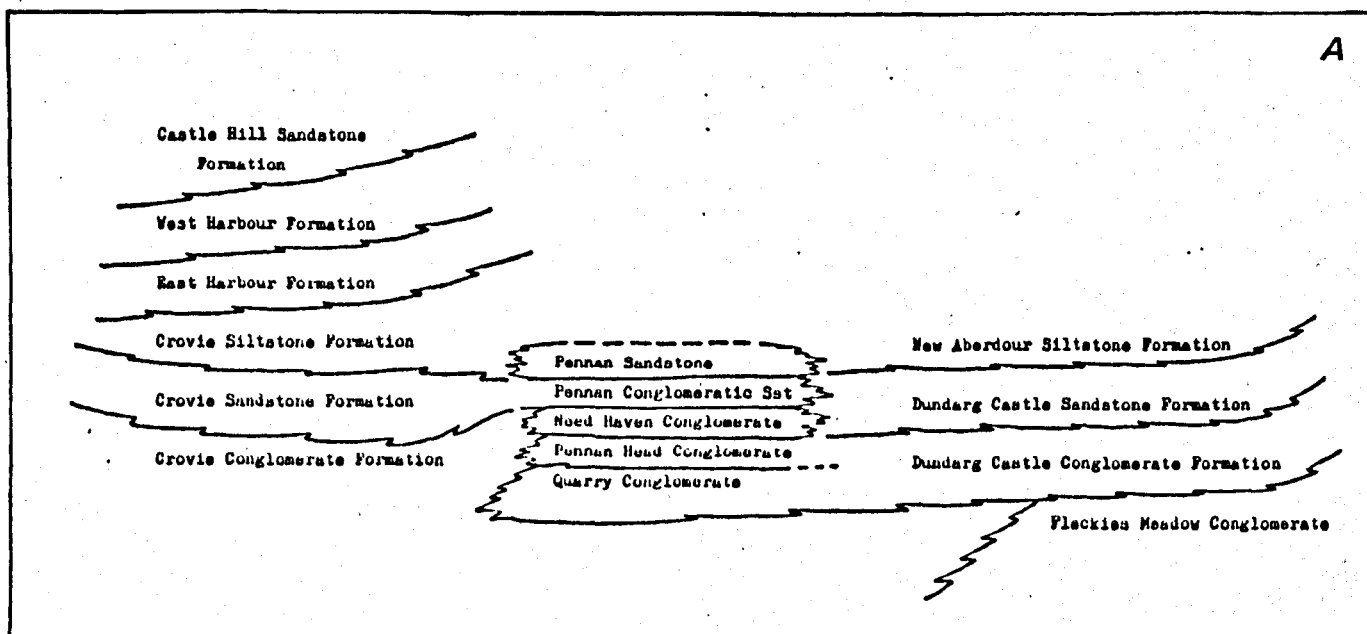


Figure 1.50 Logged profile through the Findon Fish Bed.

A



B

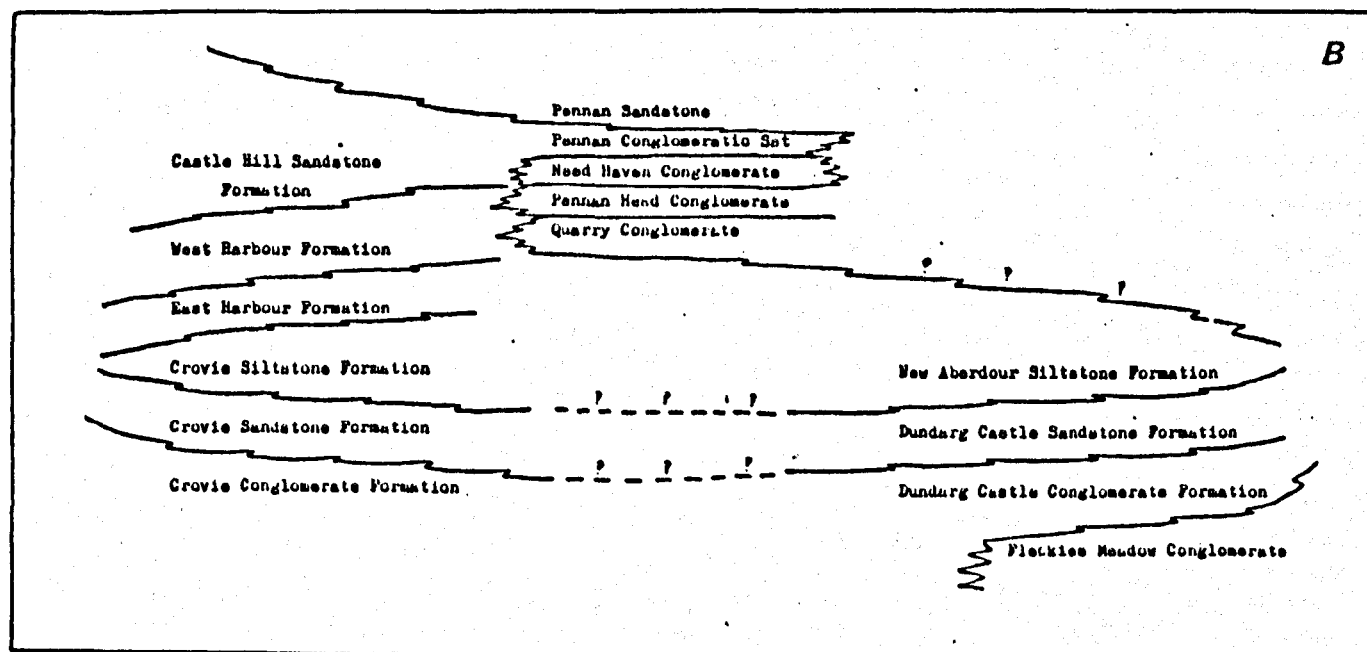


Figure 1.51 Reconstruction of possible facies relationships between the East, West and Central Coastal Sections.

Plate 1.1 Crovie Conglomerate Formation.

- A. Note abundant slate-rich detritus, set in a gravelly, sand-poor matrix. Bedding is indistinct, although a crude alignment of slate clasts is apparent. (scale 2cm squares)
- B. As above, but bedding is displayed by a textural change (level with notebook); such textural changes are often the only means of discerning bedding. (scale as above).



a



b

Plate 1.2 Crovie Sandstone Formation.

- A. Lowest deposits of the Crovie Sandstone Formation, showing interbedded sandstones and slate-rich conglomerates.

Relatively thick conglomerate units (a) interbed with thick sandstones (d).

Conglomerates may show channelled forms, with low angle cross-stratification displayed by interbedded sandstones (c and b). (scale : hammer 60cm).

- B. Flat bedded sandstone forming a whole coarse member.

- C. Typical sandstone portion of a cycle.

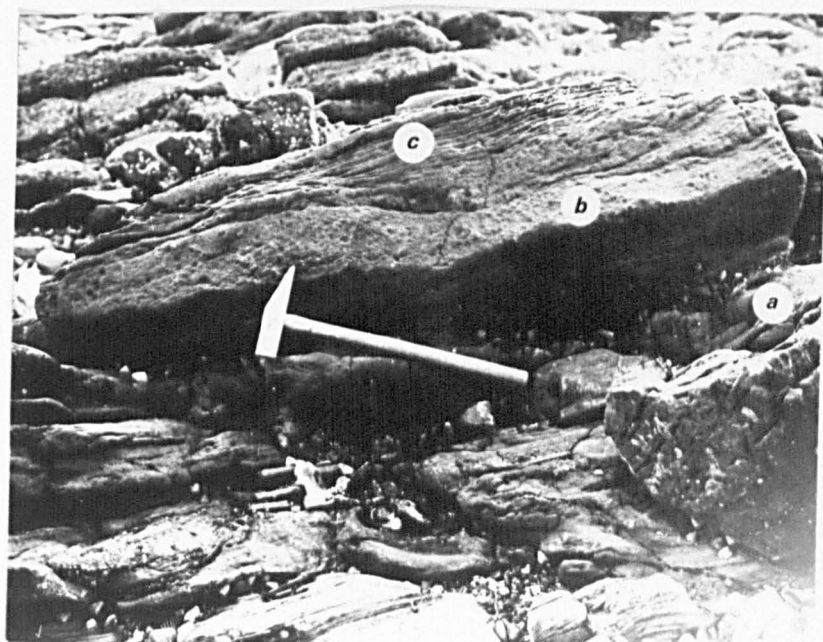
Sandstone rests upon siltstone (a), and over most of the cycle is massive (b). Towards the top of the cycle, flat bedding develops (c) and may occasionally show ripple-lamination.



a

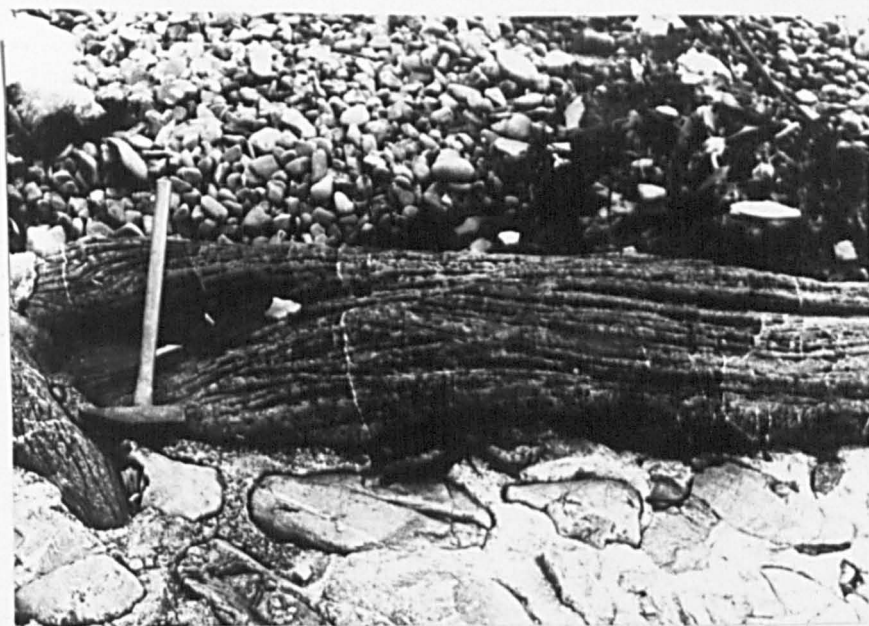


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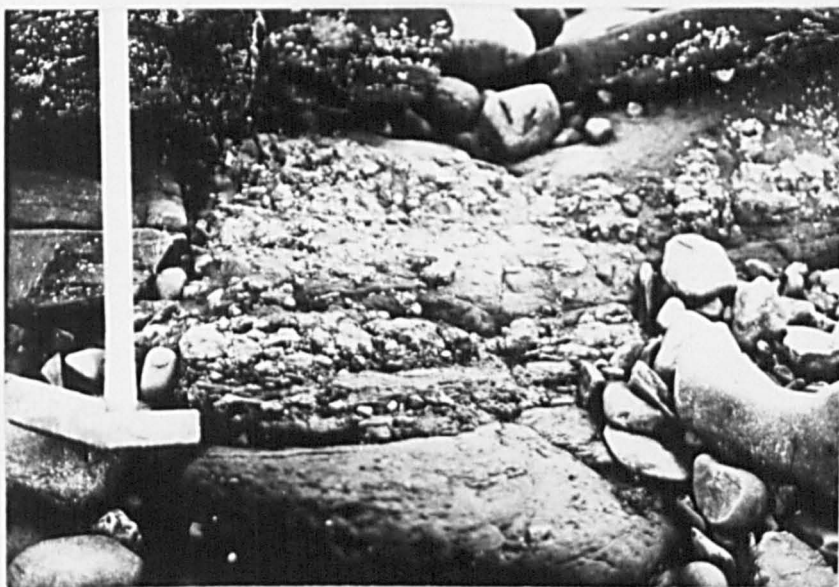


c

- A. Cross-stratified sandstone unit laterally resting with slightly erosive contact upon siltstone.
- B. Siltstone portion of a cycle showing the extensive development of calcrete nodules.
- C. Siltstone portion of a cycle showing rare evidence of desiccation (a), and slight development of symmetrical ripple marks.



a



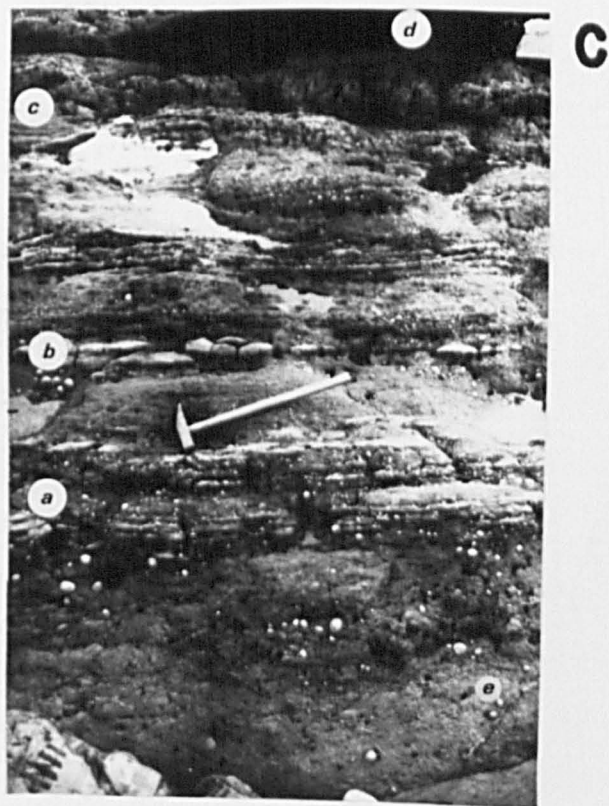
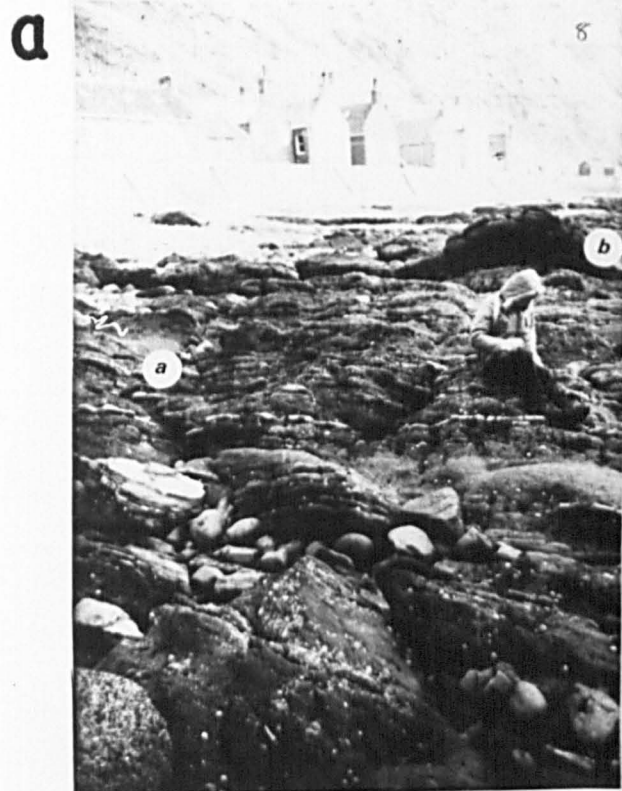
b



c

- A. Lowest portion of the sequence showing the rapid interdigitation of thin sandstones and siltstones (a), with occasional thick sandstone units still present (b).
- B. Thick generally massive portion of the siltstone sequence. Mostly, the sequence is massive (a), but calcrete nodules may be present in upper parts of the siltstone units at lower stratigraphic levels.
- C. More typical form of the siltstone sequence showing massive siltstones with calcrete nodules (e) with interdigitation of thin sandstones (a), and at higher stratigraphic levels, distinct sheets of elongate nodules (b).
- D. Detailed form of a cycle from the uppermost portion of the siltstone sequence.
 - (a) previous siltstone is overlain sharply by -
 - (b) flat bedded sandstone with low erosion surfaces.
 - (c) Grain size grades from medium to fine sandstone and-
 - (d) climbing ripple cross-lamination develops.
 - (e and f) thin, graded, massive sandstone sheets occur separated by thin siltstone veneers.
 - (g) Massive siltstone follows with very thin sandstone strings at (h), (i), and (j).
 - (k) Finally, massive siltstone follows for several metres.

(scales: hammer 60cm,
board 2cm squares)



- A. General form of wavy-bedded lithofacies:
 - (a) siltstone,
 - (b) massive sandstone,
 - (c) flat-bedded sandstone,
 - (d) crude development of ripple-drift,
 - (e) low-angle climbing ripple cross-lamination,
 - (f) siltstone.

- B. Mudstone with evidence of desiccation.

- C. Wavy-bedded lithofacies consisting of essentially sandstone with massive sandstone at the base (b), overlain by fine sandstone with thin silt veneers (c).

- D. Thick siltstone with multiple incursions of thin fine sandstone sheets and occasional sheets of calcareous nodules (b).

- E. Mudstone with distinct symmetric ripples.

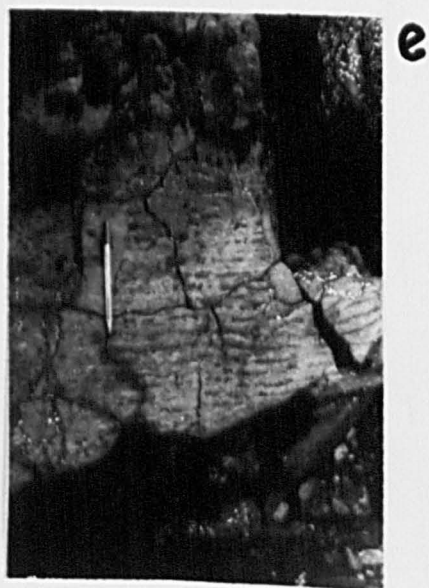
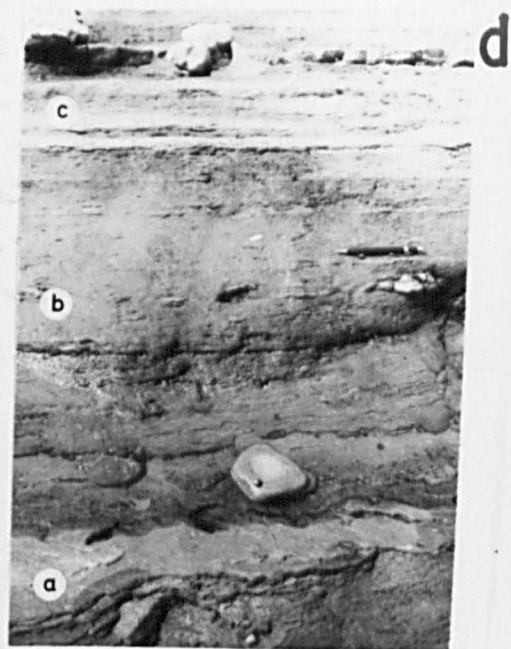
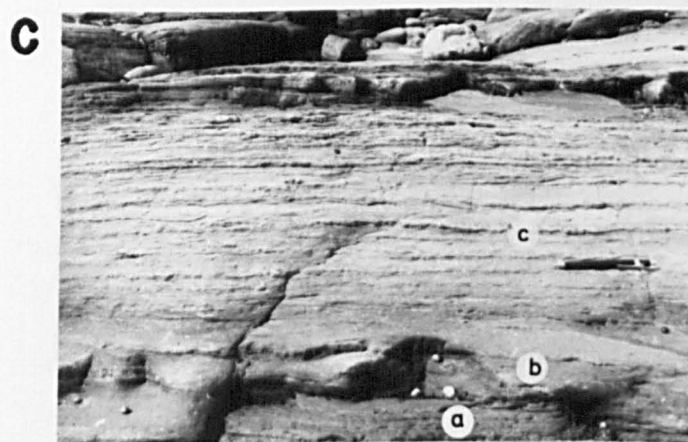
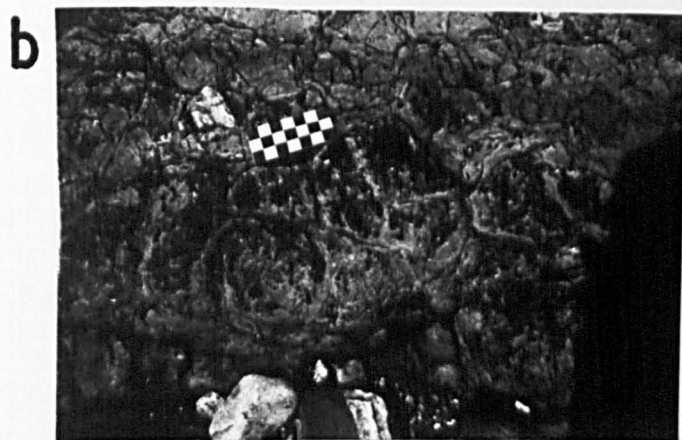
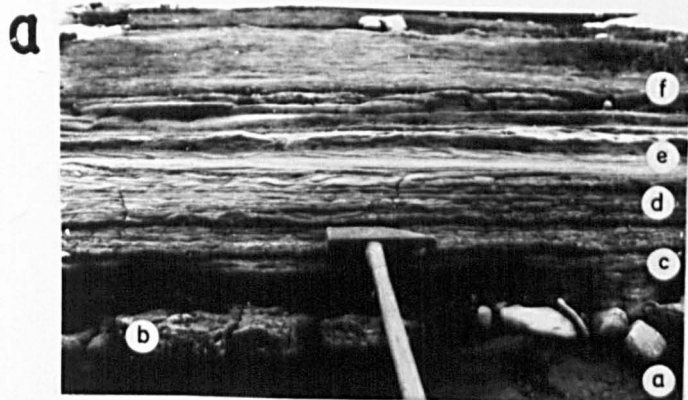


Plate 1.6 The West Harbour Formation.

- A. General form of the lower West Harbour Formation sequence, showing the interdigitation of laterally persistent sandstone and siltstone units.

- B. Lower part of photograph shows the lateral persistence of cycles (sandstone grading into siltstone). Rarely, thick sandstones may wedge out laterally (X) due to erosion, and form the margin to a channel sandstone (at higher levels only).

- C. Rare development of planar or avalanche front cross-stratification in the lower West Harbour Member.

- D. Ripple drifted sandstones (X), overlain by siltstone (Y) which rapidly diminishes in grain size. The whole unit is cut into by a channel development, but note the 'parallel ' nature of the rippled sandstone infilling the channel.

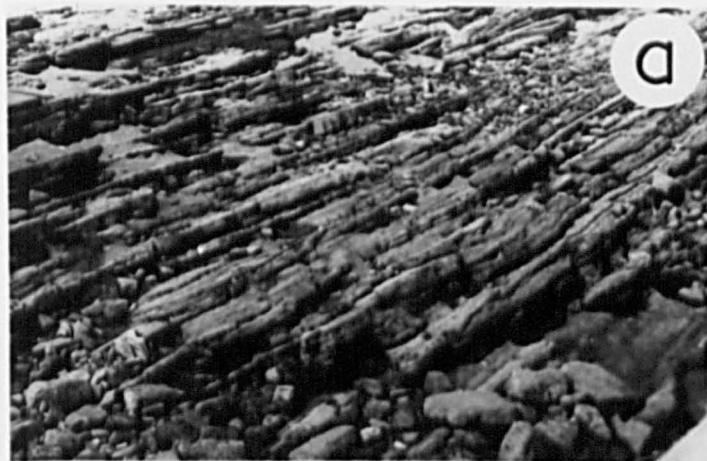


Plate 1.7 The Castle Hill Sandstone Formation.

- A. General form of the sequence, showing relatively thick, persistent, red sandstones. Note that in contrast to the underlying West Harbour Formation, the presence of very fine grained sediment is much reduced.

- B. Most commonly, sandstones show massive or flat bedding, with strings of gravel or small pebbles (a). Erosion of floodplain material is confirmed by the presence of mudflakes upon dune foresets (b).
(scale: total thickness illustrated approx 1m)

- C. At higher stratigraphic levels, sandstones become conglomeratic (c), although simple flat bedded non-conglomeratic sandstones (a) are still quite common. Small channels or erosional scours are common, infilled by cross-stratified gravelly sandstone (b).

- D. General form of the upper member, showing the predominantly conglomeratic nature of the sequence. Conglomerates are multistorey units, usually thick, and laterally persistent.
(scale : thickness illustrated approx. 4m)



Plate 1.8 Sediments of the Central Coastal Section.

The adjacent series of photographs are intended to demonstrate some of the features of the Pennan Head Conglomeratic Sandstone Facies Association. Note that many of the features are closely comparable to those found within the Dundarg Castle Conglomerate Formation.

- A. Poorly sorted, but quite well rounded detritus forming a thick but internally massive conglomerate unit.
- B. Thin laterally persistent sheets of gravel rich conglomerate demonstrating the clear abundance of 'granite sourced' feldspar gravel.
- C. Cross-stratified conglomeratic sandstone, overlain by thick poorly sorted conglomerate.
- D. Channel fill conglomerate, eroding slightly into coarse sandstone. Clasts are again quite well-rounded, and the conglomerate has a high proportion of feldspar gravel.

p



c



p



D



Plate 1.9 Sediments of the Central Coastal Section.

The adjacent series of photographs shows the general nature of the upper portion of the Pennan Head Conglomeratic Sandstone Facies Association (plates A and C), and the Need Haven Conglomerate Facies Association.

- A. Thick unit of relatively coarse sandstone, showing minor internal erosion surfaces, and thin gravel rich conglomerates. Note that feldspar gravel is very much diminished in this portion of the sequence.
- B. Conglomerates that do remain in the Pennan Head sequence are thin, low in granite and feldspar gravel, laterally persistent and interbedded with sandstones.
(scale: total thickness illustrated approx. 5m)
- C. General view of the nature of the Need Haven Conglomerate Facies Association. Note the massive nature of the conglomerate sequence, and the rare development of thin but quite persistent sandstone units.
(scale: thickness illustrated approx. 5m)
- D. Detailed view of the form of the Need Haven Conglomerate. Note the overall coarseness, relatively good-sorting, and the well-rounded nature of the clasts.
Note also that gravel, particularly feldspar gravel is absent, and that majority of the clasts are quartzite.



a



b



c



d

Plate 1.10 Sediments of the Central Coastal Section.

- A. General form of the Pennan Conglomeratic Sandstone Facies Association showing the return of large amounts of sandstone following the temporary absence of sand during the Need Haven Conglomerate sequence. The detritus is again feldspar gravel rich, and large amounts of pelitic schist are also introduced (weathering an extremely pale grey colour in this exposure).
- B. The general form of the Pennan Sandstone Facies Association. The total sequence exposed consists of conglomerate free red sandstones, showing the development of relatively large trough cross-stratified units.



a

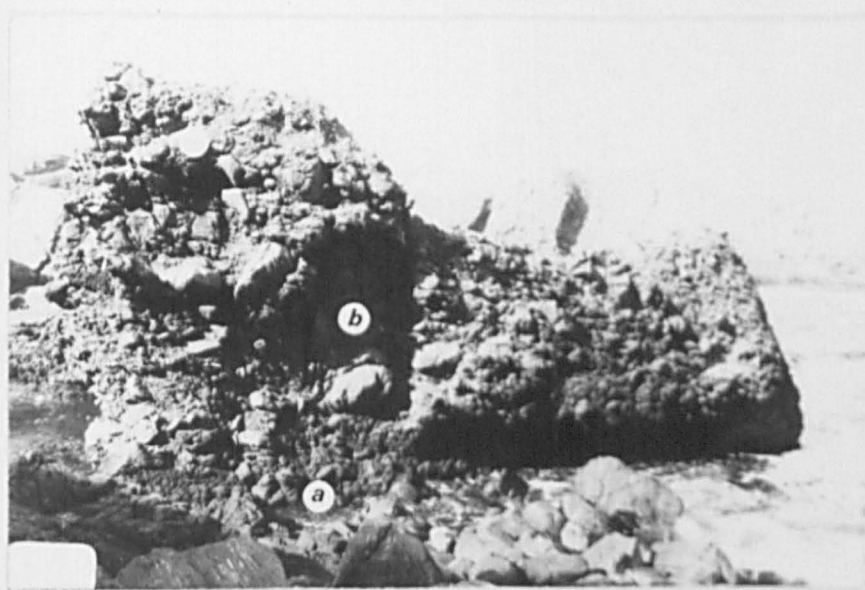


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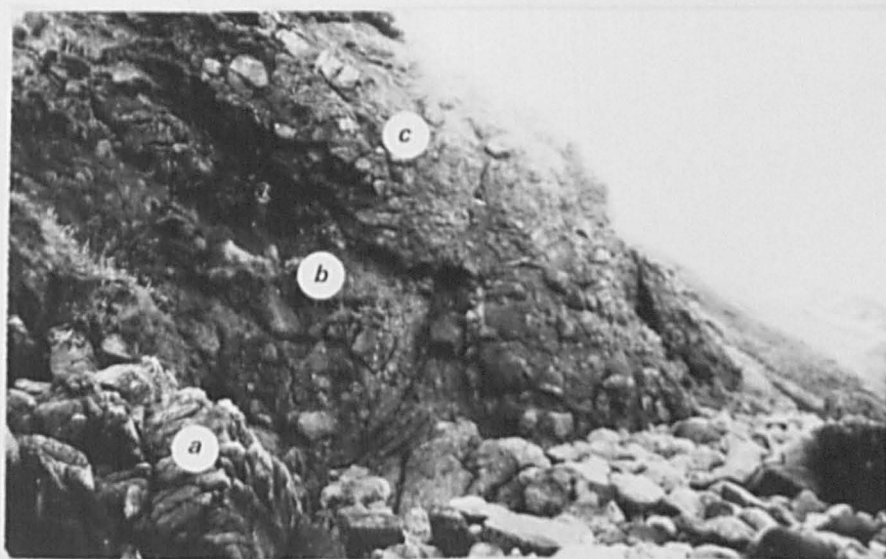
- A. Coarse, poorly-sorted nature of the basal conglomerates at Quarryhead. Note that clasts are poorly rounded, and predominantly of psammitic schist.
- B. Gully' filling conglomerate at Quarryhead shown resting upon the Dalradian Basement high spots (a). For scale, the deeply weathered boulder (b) measures $4\frac{1}{2}$ m from top to bottom. Again, note the very poor-sorting.
- C. Considerable basement relief exists at Quarryhead, Dalradian basement (a) is here deeply eroded (b) and infilled by very poorly-sorted conglomerate (c). (scale: total thickness exposed approx 6m)



a

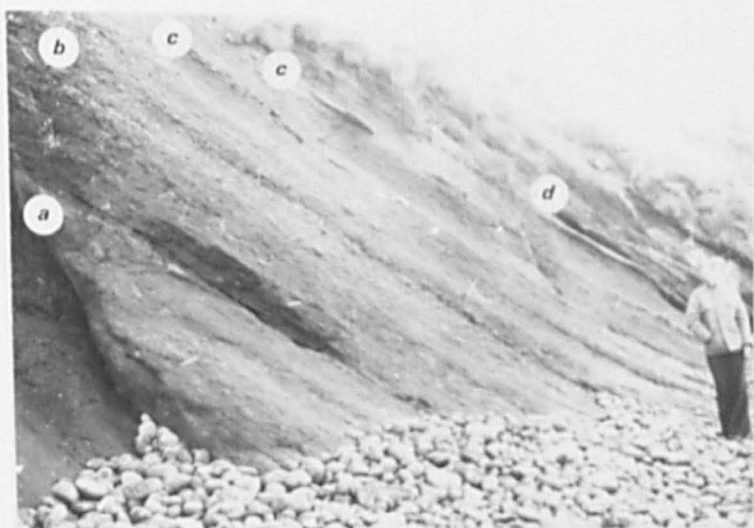


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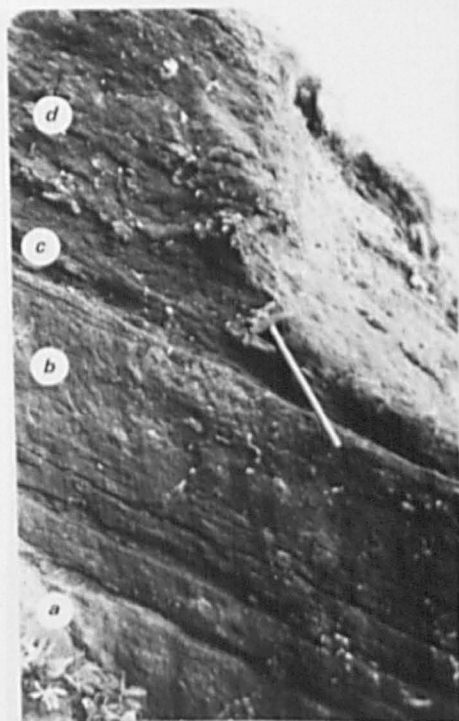


c

- A. Floodplain siltstones with abundant calcareous nodules at the south end of Quarryhead Bay.
- B. Gravelly sandstones (a and b) overlain by siltstones with abundant carbonate nodules.
- C. Coarse nature, poor rounding, and poor-sorting of the basal 'gully' fill conglomerates. The boulder (A) is also figured in plate 1.11 B and measures $4\frac{1}{2}$ m in maximum dimension.
- D. Distal portion of the 'gully' fill conglomerate showing wedges of conglomerate (c and d) splaying from the gully fill out onto the floodplain sandstones (b). Note that very large blocks have still been transported (e). The Dalradian basement (a) represents the edge of the adjacent deep gully.



a



b



c



d

Plate 1.13 Sediments at the base of the Eastern Coastal Section,
at Fleckies Meadow.

- A. Deep Dalradian depression (a) overlain by a thin covering of Lower Old Red Sandstone basal conglomerate.

- B. Indistinct plane of unconformity (a) / (b) with the Dundarg Castle Conglomerate (a) resting directly upon the Dalradian basement (b) at this locality.

- C. Detail of the plane of unconformity, showing the abundance of 'spotted' andalusite schist (a) immediately below the unconformity. Large blocks of similar schist (c) occur just above the unconformity, but mostly, the debris is psammitic schist (b).

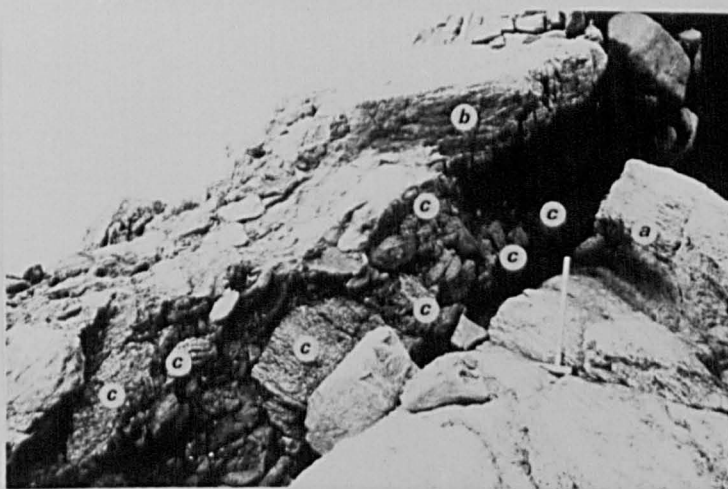
- D. Vertical cliff like terrace within the Dalradian basement (a), with an overlying scree of Lower Old Red Sandstone (fleckies Meadow) conglomerate (b).



a



b



c



d

- A. General view of the nature of the outcrop of the Dundarg Castle Conglomerate sequence (west of Boat Shore).

- B. Close up view of portion of the above exposure, showing the typical form of the Dundarg Castle Conglomerate sequence.
Note the predominance of gravel rich horizontally bedded sandstones, and impersistent coarse conglomerates.

- C. Further general view of the Conglomerate sequence, this time showing more abundant 'multiple conglomerate sheets'.



a



b



c

Plate 1.15 Sediments of the Dundarg Castle Conglomerate Formation.

- A. Coarse channel fill conglomerates interbedded with gravel rich sandstones. (scale: thickness exposed 10m)

- B. Thinly bedded gravels with small scours and minor erosion surfaces possibly of aeolian origin.
(scale: thickness exposed 4m)

- C. Major channel structure, showing :
 - (b) coarse conglomerate at base of channel, and rising up into low-angle cross stratified conglomeratic sandstones.
 - (a) whole channel deposit overlain by a multistorey conglomerate unit.

- D. Distinct single sheet conglomerate (a) overlain by a thin persistent sheet of granule rich sandstone.

- E. Channel fill conglomerate (b') overlying cross-stratified gravel rich sandstones (a).

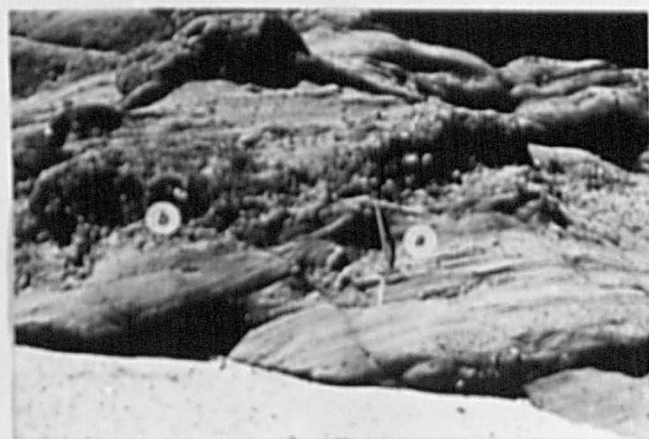
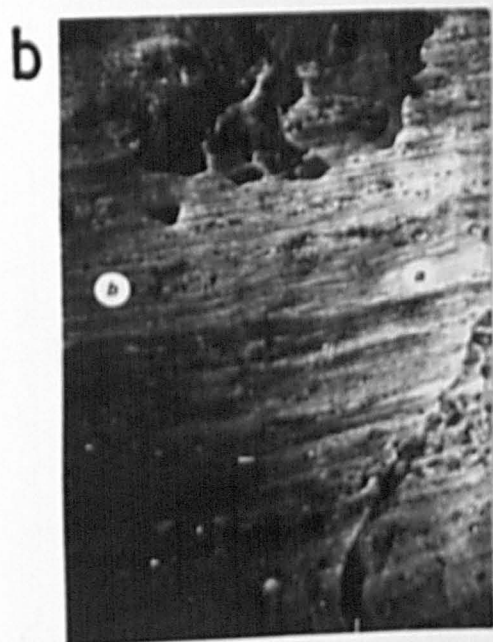
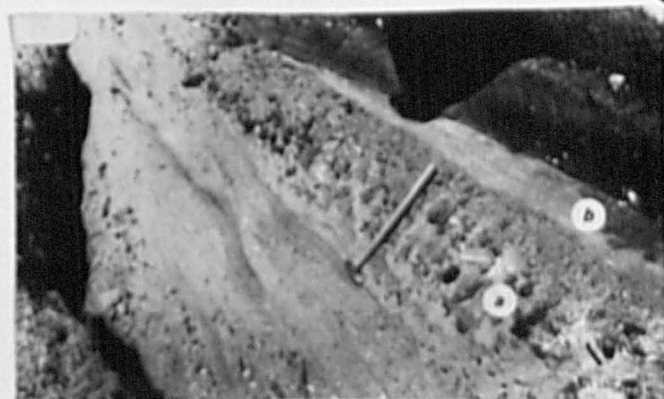
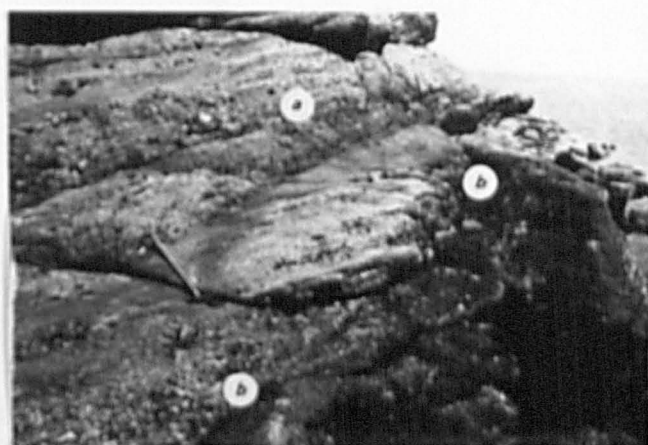
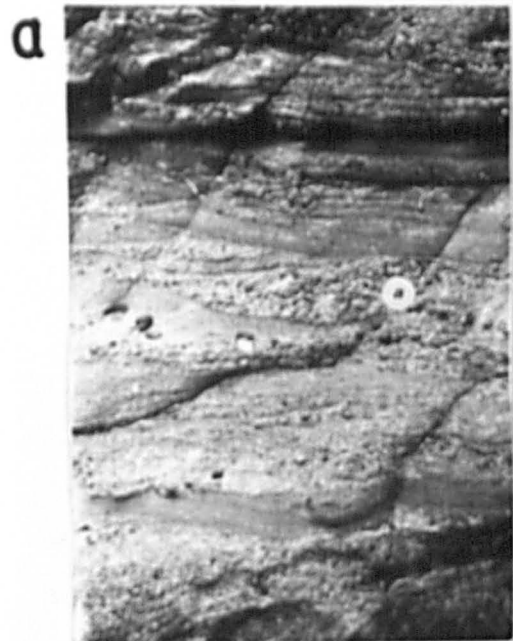


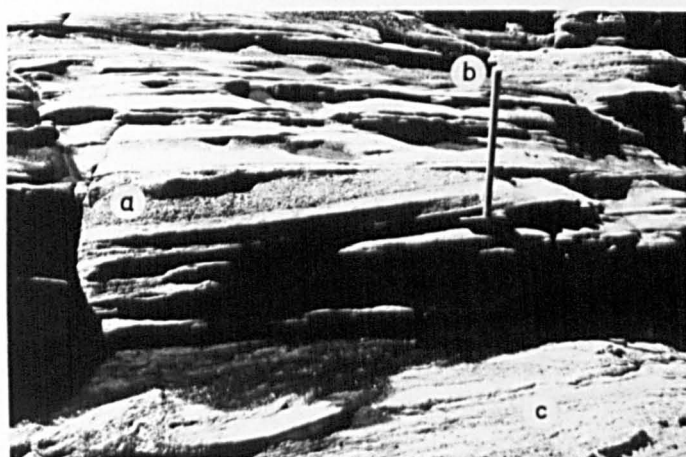
Plate 1.16 The Dundarg Castle Sandstone Formation.

- A. The junction between the Dundarg Castle Conglomerate Formation (a) and the overlying Dundarg Castle Sandstone Formation (b and c). Note the great impersistence of deposits within the conglomerate sequence, in contrast to those of the sandstone sequence.
- B. Massive gravel in broad channel units (a and b). Note that gravels are thin , but persist laterally.
- C. Thinly interbedded sandstone and gravelly sandstone, note the presence of very thin dark siltstone veneers (c).
- D. Thinly bedded fine sandstones, generally massive, but occasionally showing crude ripple drift lamination.
- E. Further illustration of broad gravel channel infills. Note that gravels are truly massive, with gravel fragments floating within a fine gravel / granule rich sandstone matrix.

a



b



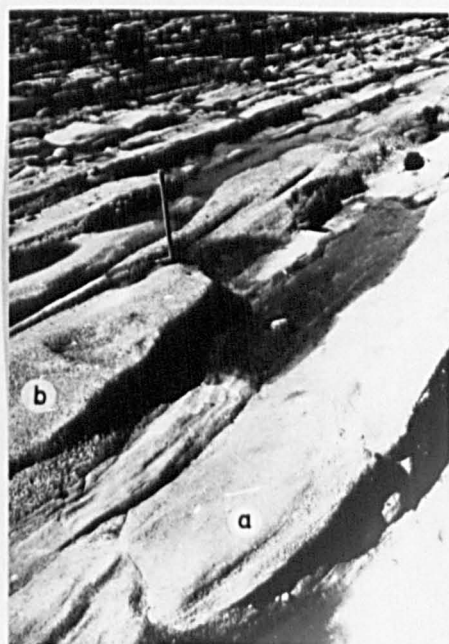
c



d



e



A selection of photographs showing the main features of the New Aberdour Siltstone sequence, and illustrating the rapid interbedding of sandstone and siltstone in coarse portions of cycles (plates A, C and D).

The siltstones are shown to be relatively massive in appearance (plates B and D) although strings of calcareous nodules are common within such units (plate B (a), (b)). Furthermore, evidence of desiccation, although uncommon, is distinct (plate E).

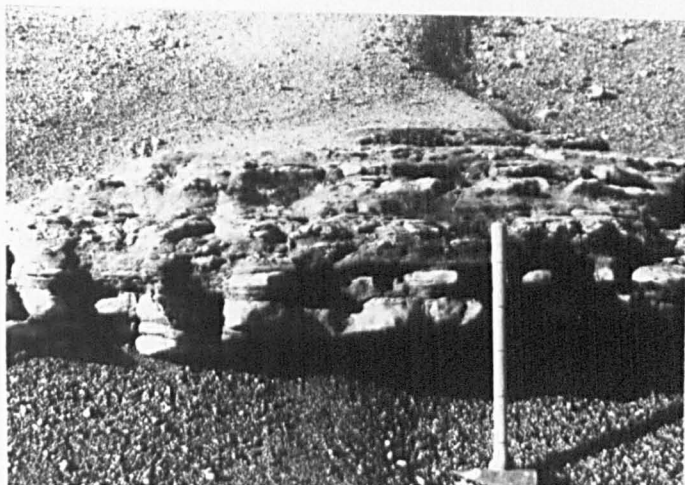
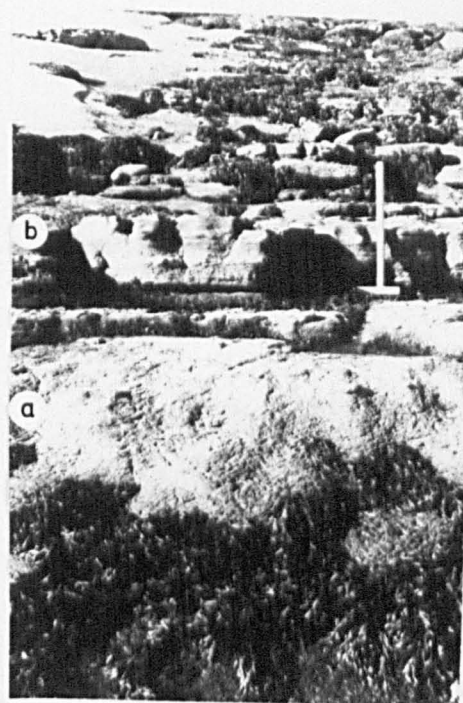
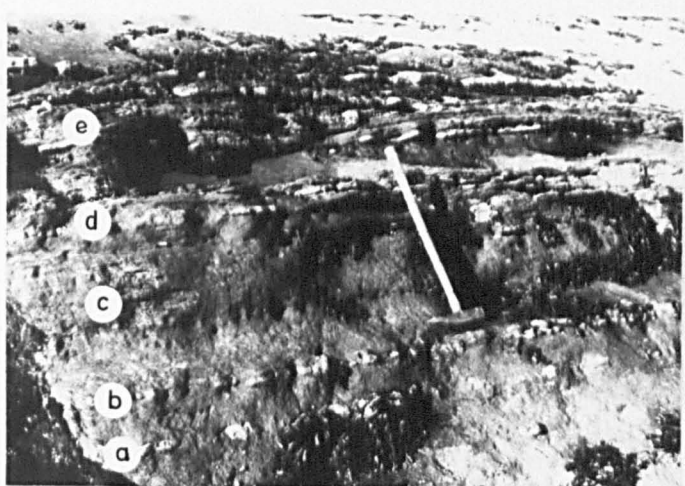
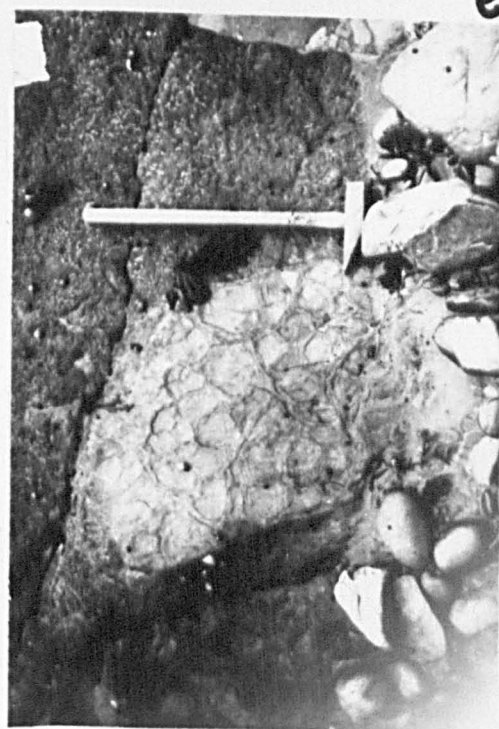
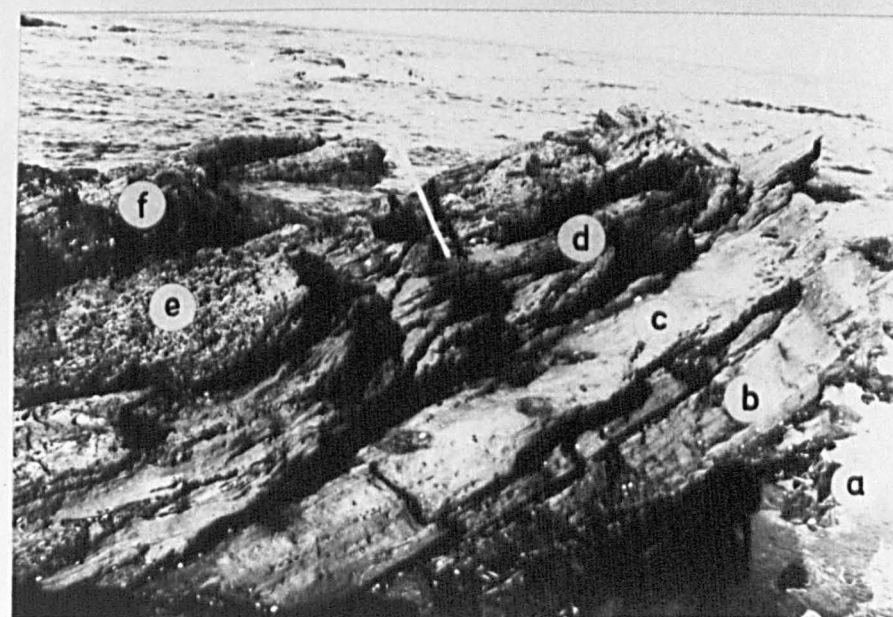
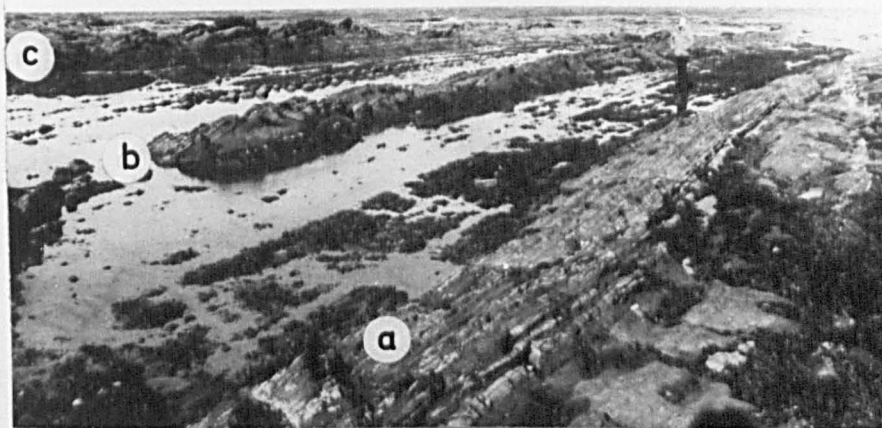
a**d****b****e****c**

Plate 1.18 The New Aberdour Siltstone Formation.

- A. A general view of the siltstone sequence showing the laterally persistent cycles based by thinly bedded sandstones (a, b, and c), and alternating with thick, soft, siltstones.

- B. Detail of one such cycle, showing the sandstone base to the cycle (a) and the overlying siltstone with numerous persistent sheets of calcareous nodules (b).

- C. A section through part of the coarse member at the top of the siltstone sequence.
 - (a) thick siltstone overlain by flat bedded sandstones (b) and eventually gravelly sandstones (c) before being capped by cross-stratified sandstones (d and e). Siltstone overlies the whole unit sharply (f).

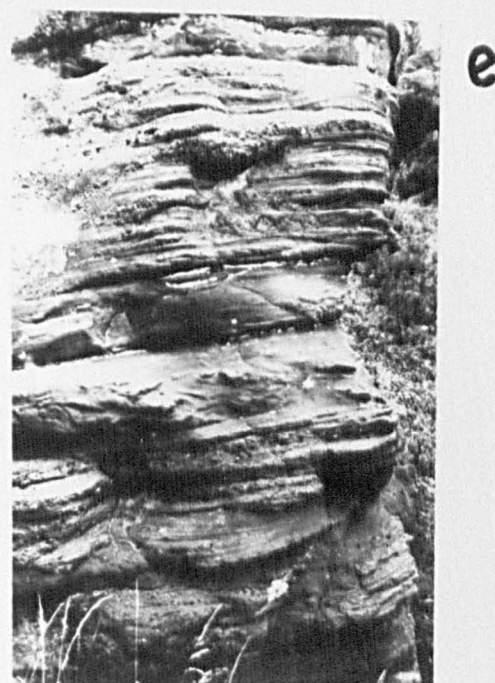
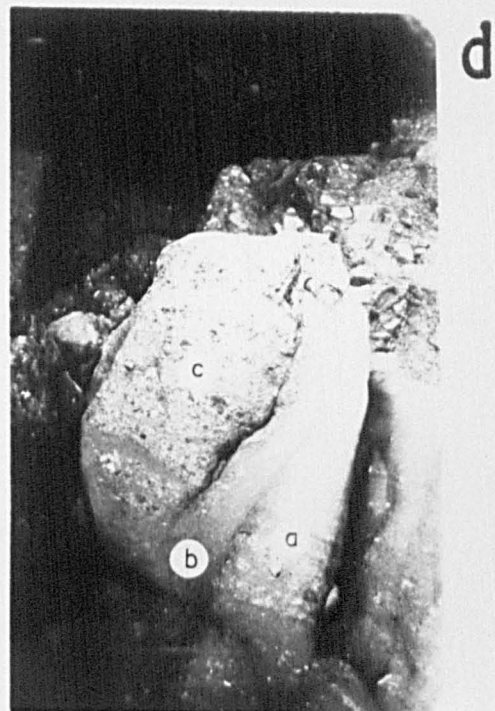
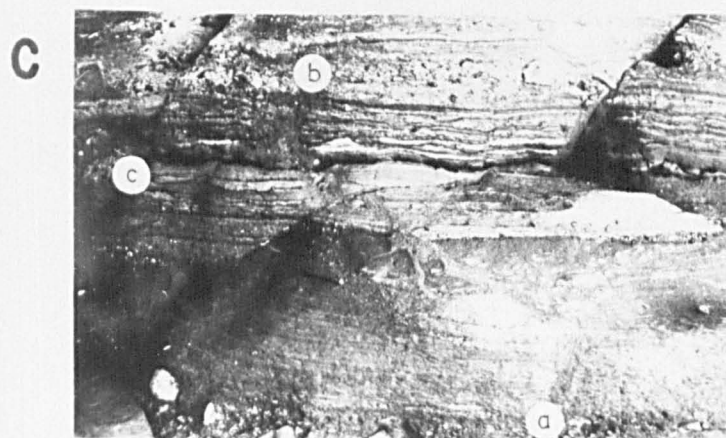
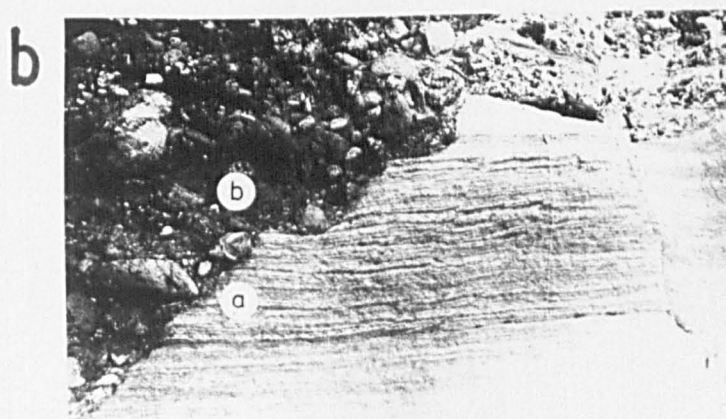
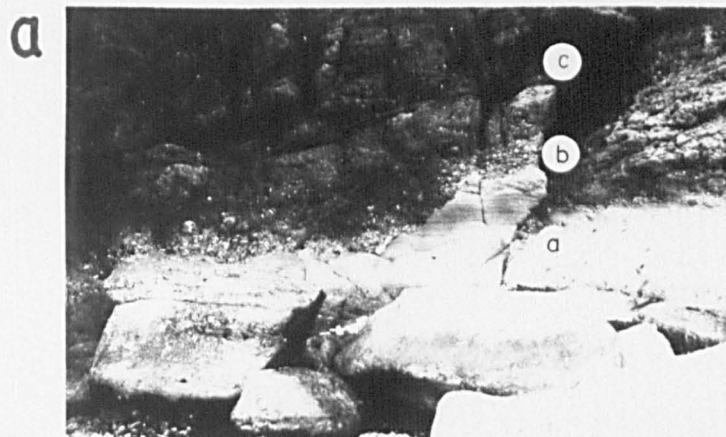


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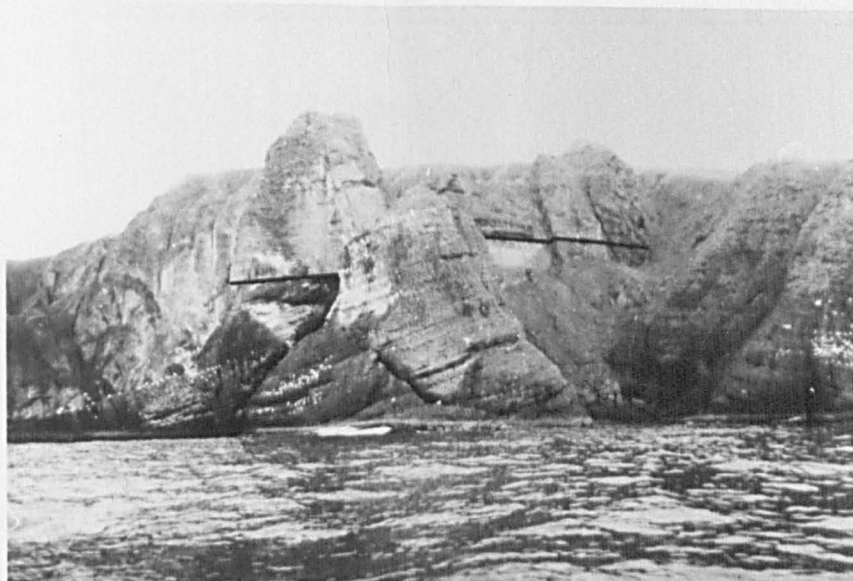
c

Plate 1.19 A Details of the Middle Old Red Sandstone Unconformity
beneath 'the Lodge' near Pennan.

- A. Lower Old Red Sandstone sediments (a) showing the stepped erosion surface (b), overlain by reworked L.O.R.S. conglomerate, prior to the slate rich M.O.R.S conglomerates (c).
- B. Detail of the unconformity, note the reverse rotational minor faults developed within the lower sandstones (a).
- C. Sand injection structures within the lower sandstones (a-b),
- D. Slumped sediment (b) down the side of one of the small steps in the plain of unconformity.
- E. General nature of the sediments beneath the unconformity, note the similarity to sediments of the Dundarg Castle Conglomerate sequence.



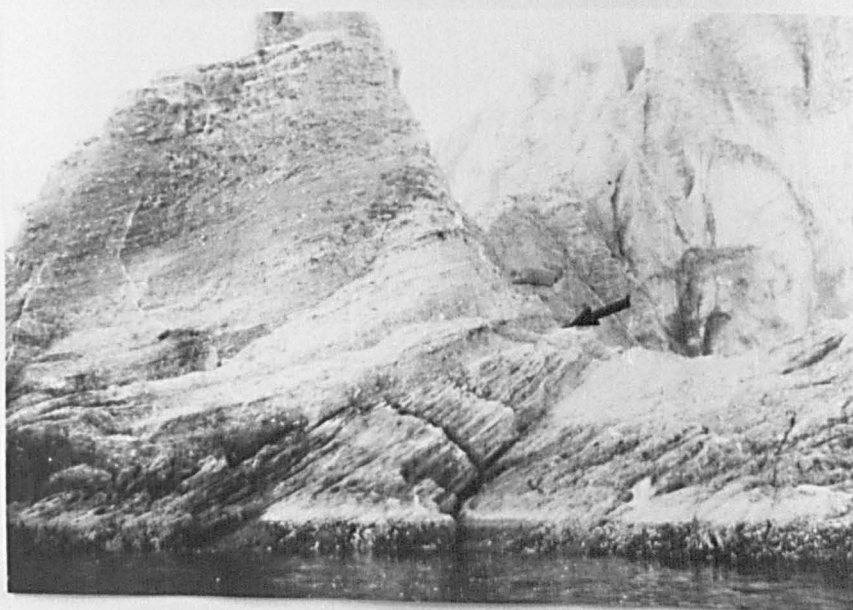
- A. Outcrop of the distinct plane of unconformity between Lower and Middle Old Red Sandstone conglomerates in 'Meal Girnel'.
- B. Planar form of the unconformity displayed in the western side of 'Sidegate'. Note the distinct angular discordance.
- C. Close up view (from the sea) of the slightly irregular plane of unconformity as exposed on the promontory between 'Sidegate' and 'Langlitterty'.



a



b

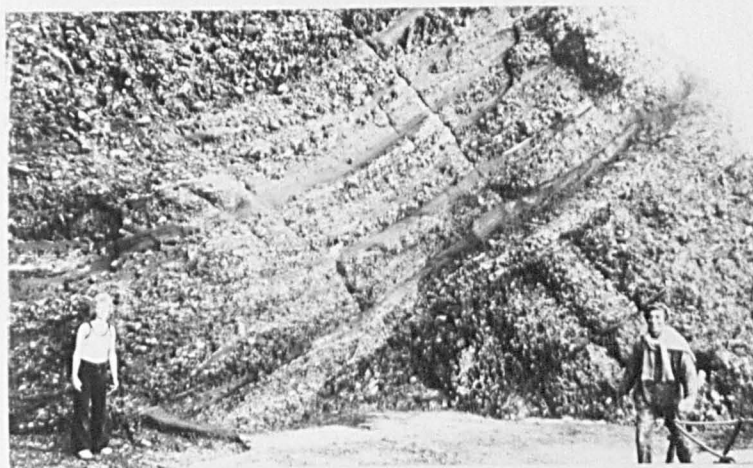


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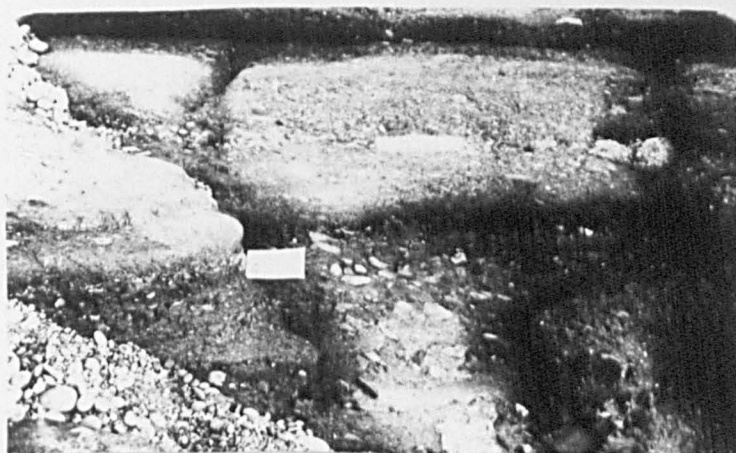
- A. General appearance of the Middle Old Red Sandstone slate-rich conglomerates outcropping in the Central Coastal Section. The plate shows the M.O.R.S. conglomerates in 'Strabackie', where the cliffs, in excess of 100m in height, are composed of an unbroken sequence of conglomerate.
- B. Middle Old Red Sandstone conglomerates exposed at the 'Snook' near Gardenstown.
At this locality, the conglomerate composition strongly reflects the Lower Old Red Sandstone composition, and is considered to indicate that these conglomerates are reworked Lower Old Red Sandstone detritus.
- C. 'Typical' slate rich Middle Old Red Sandstone Conglomerate outcropping at Mill Shore to the West of Pennan.
Note that slate detritus predominates, and that a slight imbrication is developed, in this case showing transport to the north (left).
- D. Slate rich Middle Old Red Sandstone conglomerate from Mill Shore showing an unusual form of clast packing, Note that over a short lateral distance the blade / disc shaped clasts are vertically packed.



a



b



c



d

Plate 1.22 The Findon Fish Bed, Den of Findon.

- A. General appearance of the present outcrop of the Findon Fish Bed (x), showing the rapidly deteriorating nature of the exposure.

- B. The upper portion of the Fish Bed showing pale grey mudstones (a), overlain by reddened mudstones (b) containing abundant calcrete nodules.

- C. Grey shaley mudstones, containing elliptical fish bearing nodules (a), and overlain by reddened mudstones (b) immediately beneath the erosive base of the upper Findon Conglomerate (c), (erosive base shown by dotted line).

- D. Base of the Findon Fish Bed showing the lower Findon Conglomerate (a), overlain by gravely red siltstones (b), overlain by grey green plant bearing mudstones (c).

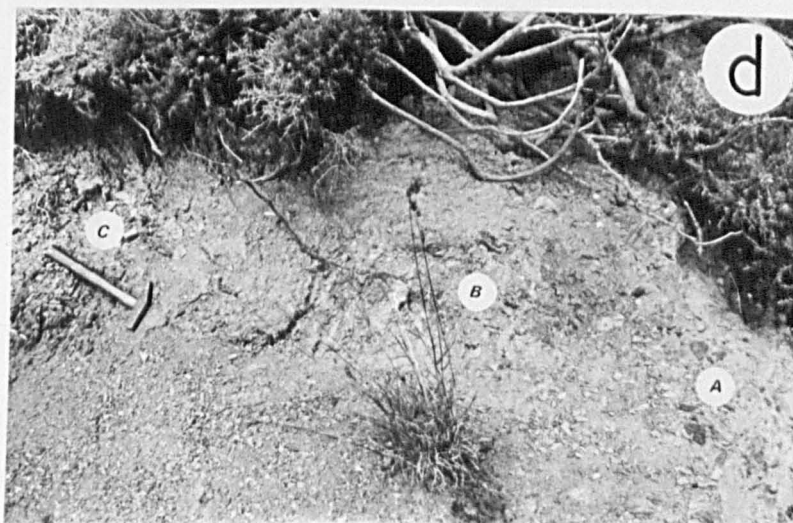
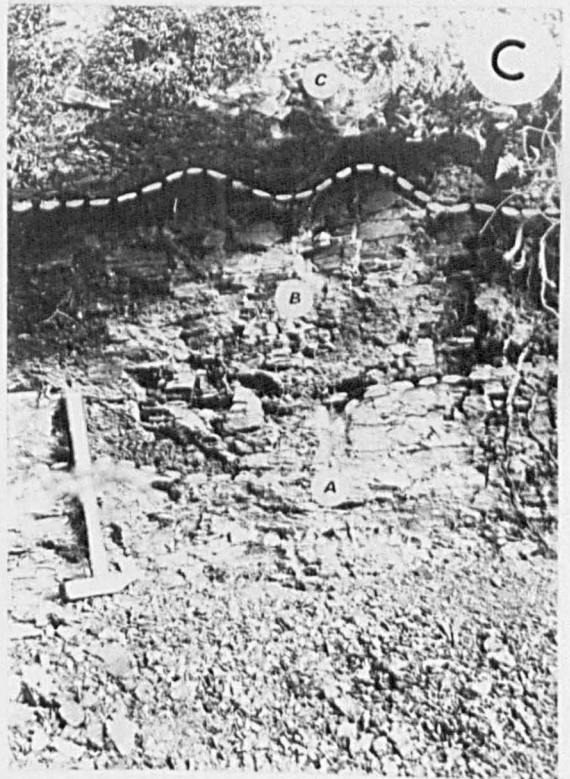
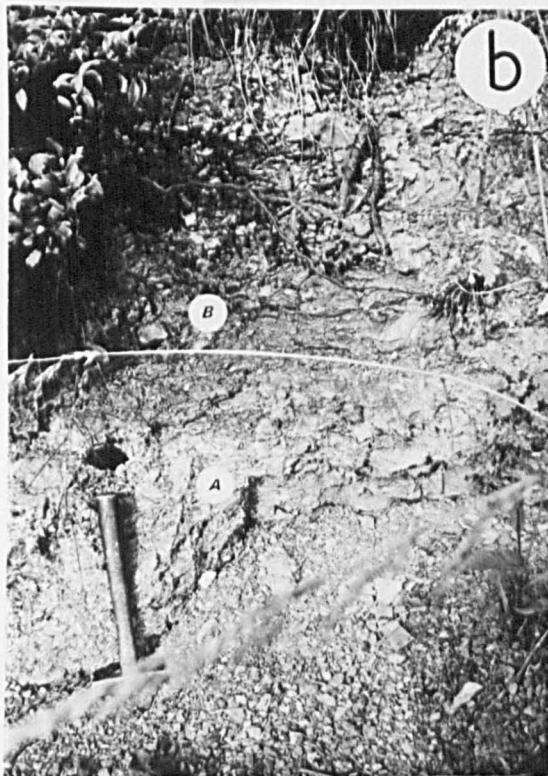
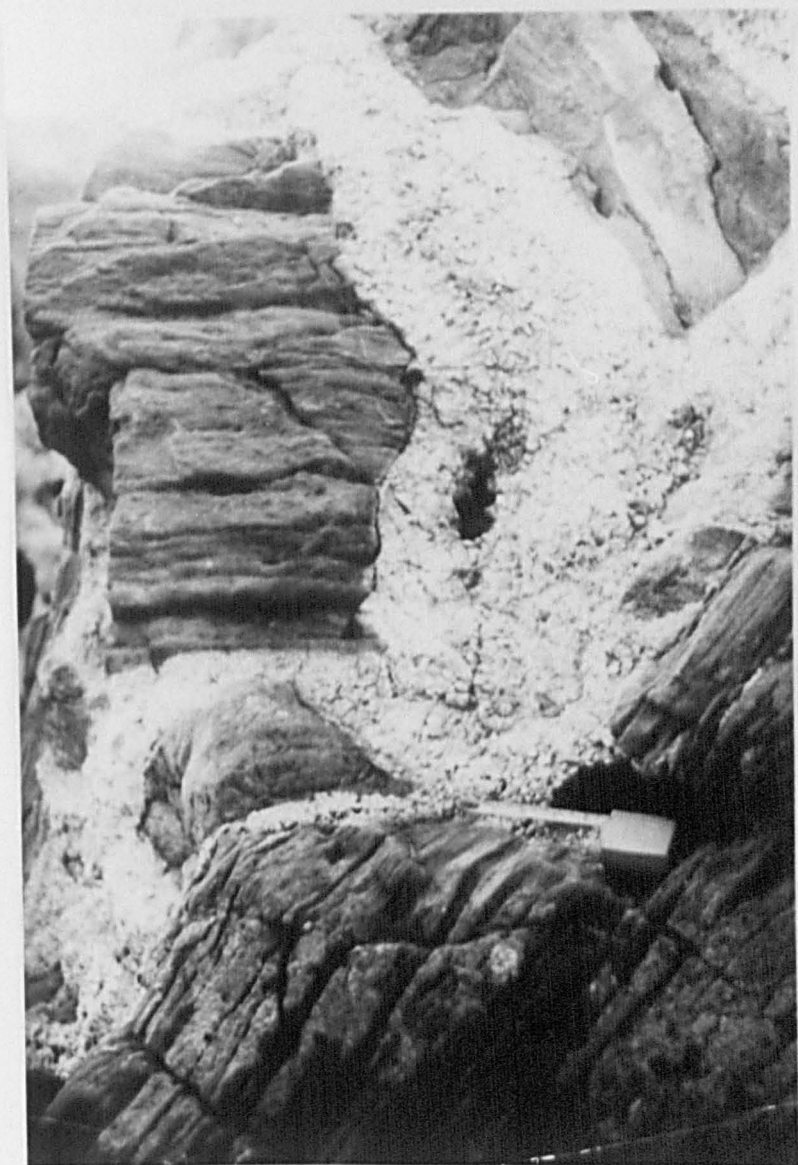


Plate 1.23

Fossil 'Karst Topography' exposed to the west of
the Gamrie Outlier at Sandend Bay.

The adjacent plate shows the thick development
of drusy sparry calcite cementing together
reorganised blocks of Dalradian Basement.



CHAPTER 2

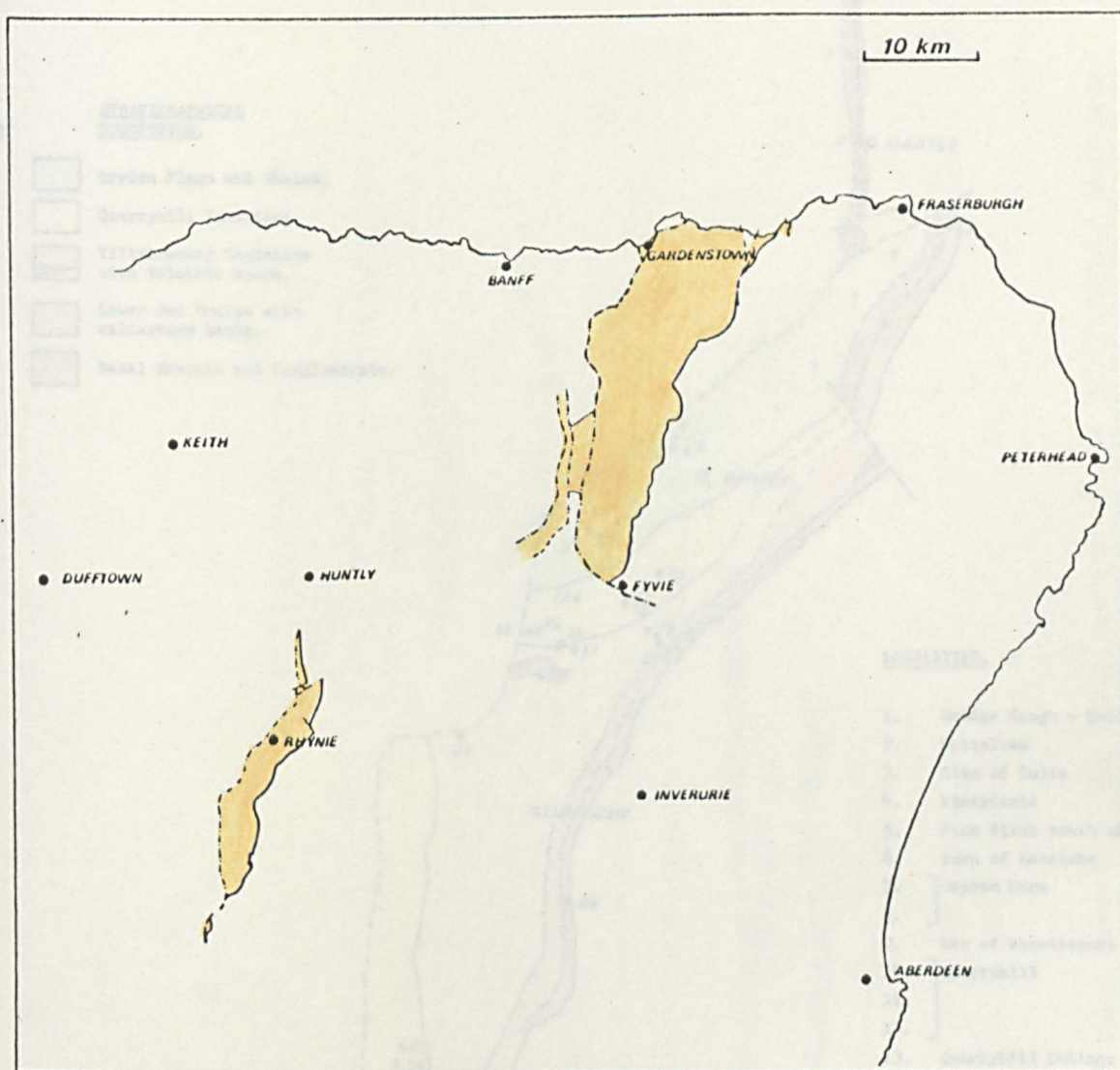
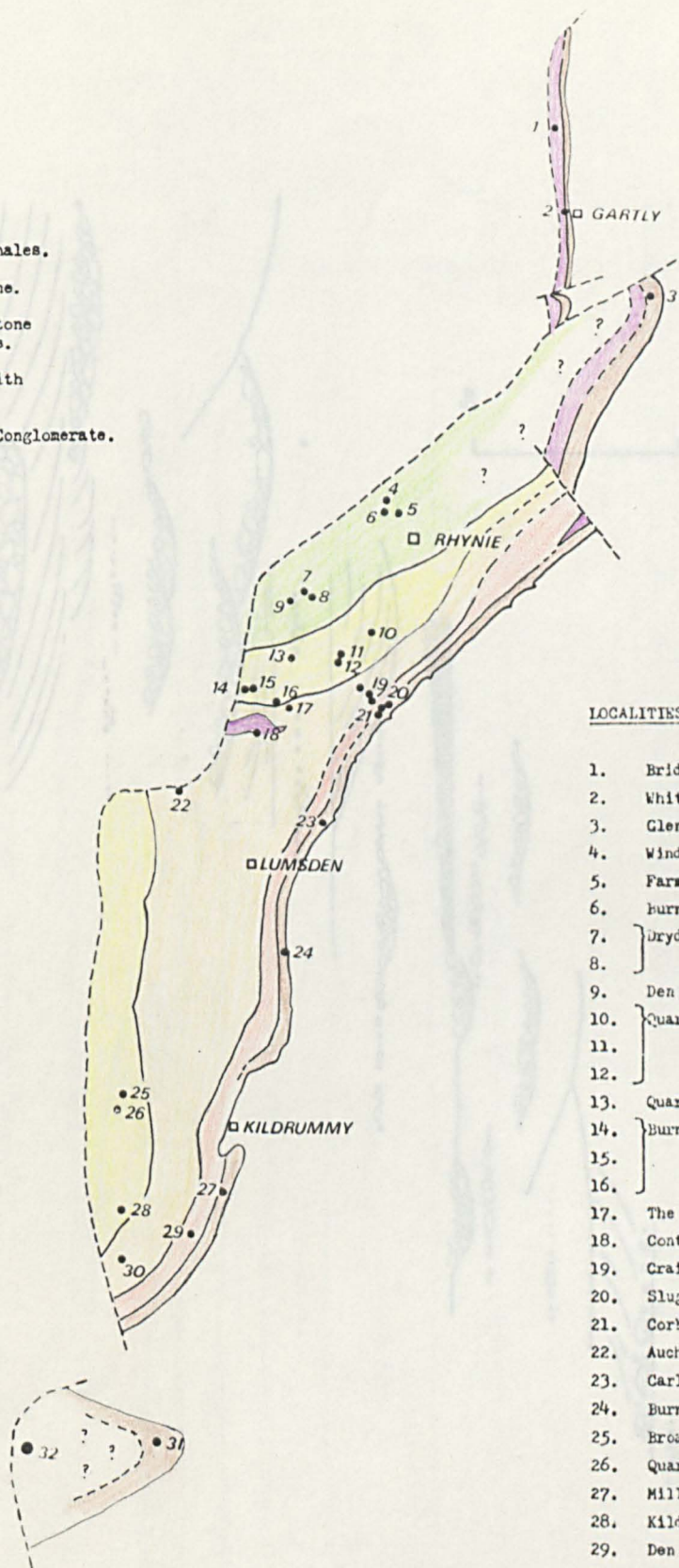


Figure 2.1 General location map showing the relative positions
of the Gamrie and Rhynie Outliers.

Figure 2.2 Geological Map of the Rhynie outlier, numbers refer
to localities mentioned in the text.

STRATIGRAPHICAL SUCCESSION.	
'Zone'	
5	Dryden Flags and Shales.
4	Quarryhill Sandstone.
3	Tillybrachty Sandstone with Volcanic zones.
2	Lower Red Shales with calcareous bands.
1	Basal Breccia and Conglomerate.



LOCALITIES.

1. Bridge Haugh - Culdrain
2. Whitelass
3. Glen of Cults
4. Windyfield
5. Farm ditch south of 4.
6. Burn of Eacaiche
7. } Dryden Farm
8. }
9. Den of Wheedlenont
10. } Quarryhill
11. }
12. }
13. Quarryhill Cottage
14. } Burn of Craig
15. }
16. }
17. The Mill (Burn of Craig)
18. Contlach
19. Craigs of Tillybrachty
20. Slughallen Burn
21. Corbies Tongue
22. Auchinleath
23. Carlinden Burn
24. Burn of Linthaugh
25. Broadley Quarry
26. Quarryfield
27. Milltown of Kildrummy
28. Kildrummy Castle Quarry ('Back Den')
29. Den of Kildrummy
30. Roadside exposures
31. Bridge of Towie
32. Towie

Figure 2.2

Geological Map of the Rhynie Outlier, numbers refer
to localities mentioned in the text.

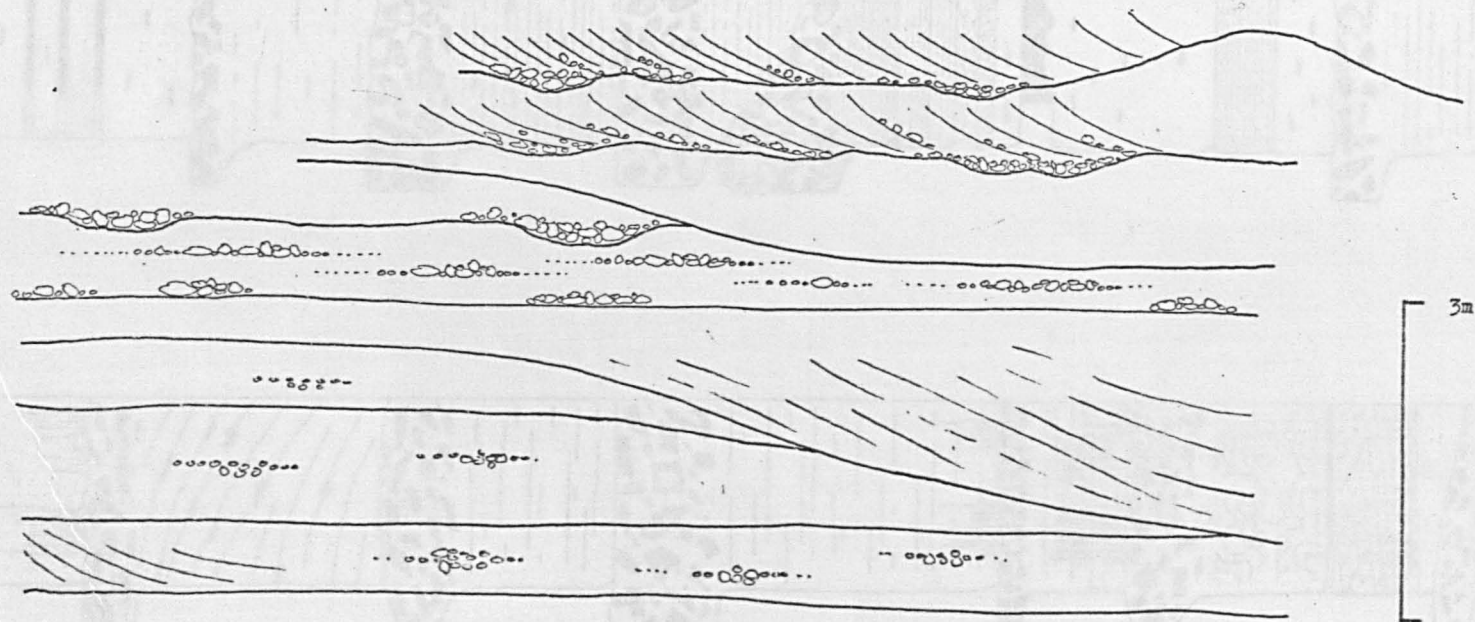


Figure 2.4 Logged section / field sketch through the upper portion of the Tillybrachty Sandstone sequence as exposed in the Craigs of Tillybrachty.



Figure 2.5 Typical field logs from the lower (A), middle (B), and upper (C) portions of the Quarryhill Sandstone.

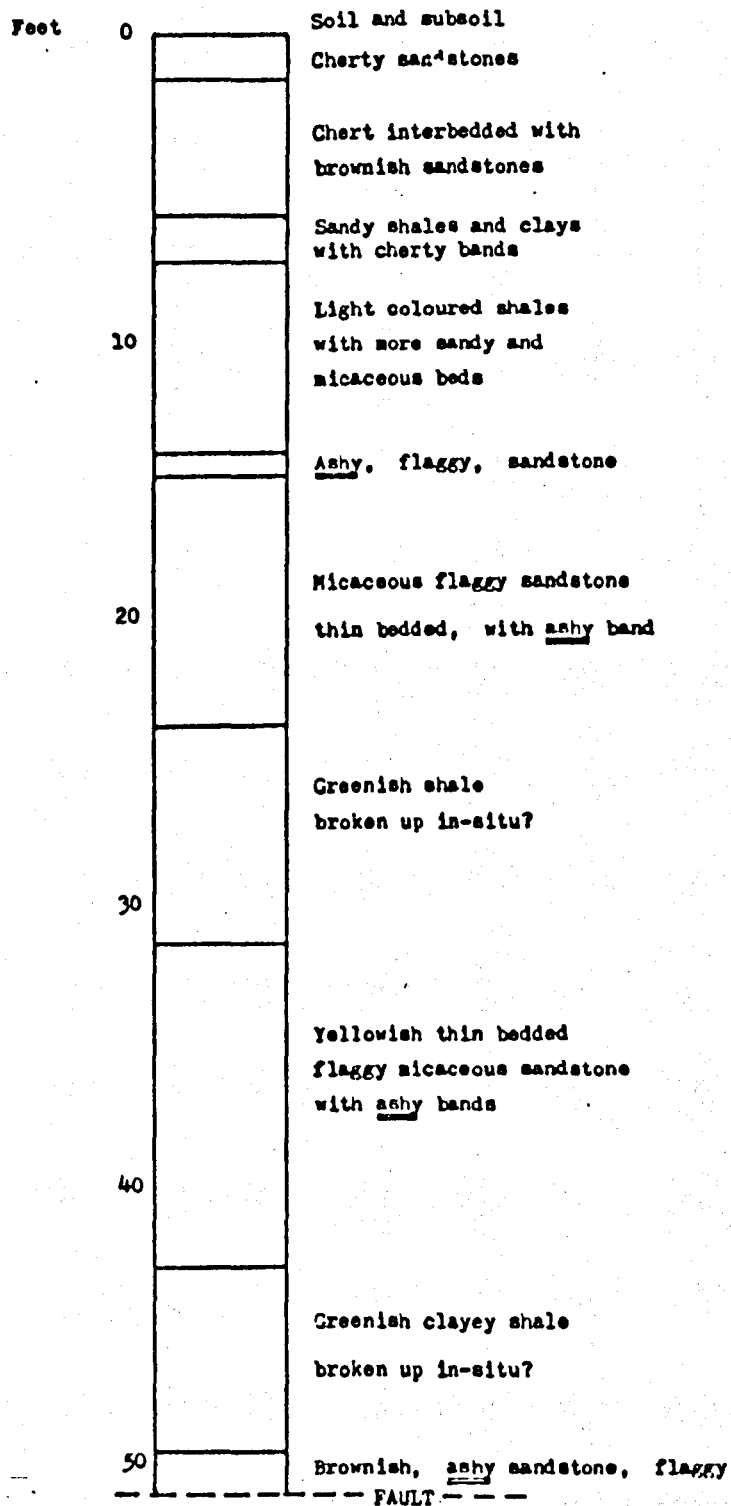


Figure 2.8

A field log through a portion of the Rhynie Chert sequence made by Horne et al (1916), note the presence of ashy horizons.

Plate 2.1 The Tillybrachty Sandstones.

- A. Lowermost conglomerates of the Tillybrachty Sandstone sequence, exposed in the Corbiestongue.
- B. As above, showing thick poorly sorted conglomerate developments interspaced with relatively thick conglomerate free sandstones.
- C. Lowermost sediments of the Craigs of Tillybrachty, stratigraphically immediately above those of the Corbiestongue, and noticeably less conglomeratic.
- D. Middle portion of the Tillybrachty Sandstone sequence (Craigs of Tillybrachty) showing the development of thin siltstone horizons, and small intraformational conglomerates.
- E. Uppermost portion of the Tillybrachty Sandstone sequence (Craigs of Tillybrachty) showing thin siltstone developments, and the introduction of small units of cross-stratification.

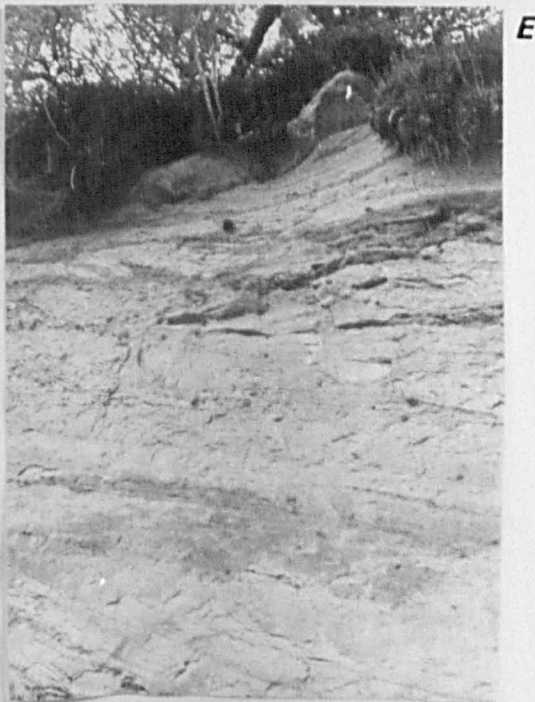
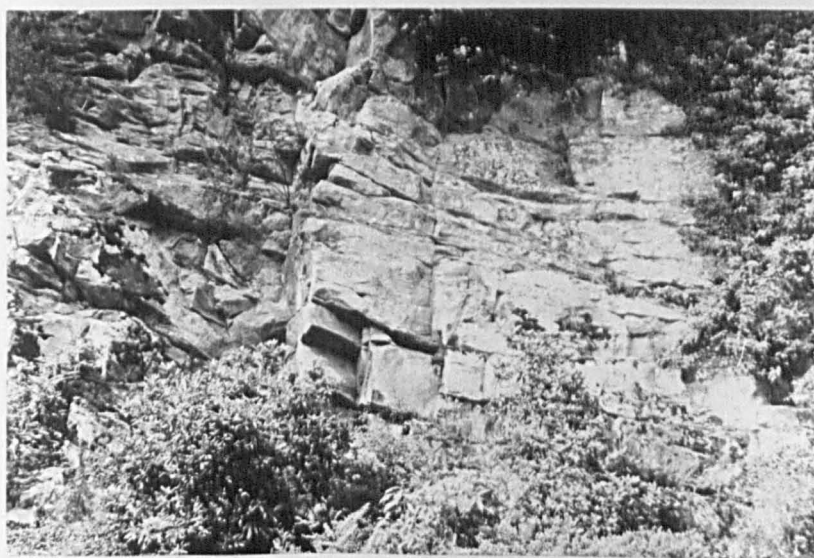


Plate 2.2 The Quarryhill Sandstone.

- A. Kildrummy Castle Quarry.
Exposure in this quarry, the lowest in the Quarryhill Sandstone sequence is largely obscured by extensive landscaping.
- B. Kildrummy Castle Quarry.
Part of the little exposure available, showing the lower portion of the Quarryhill Sandstone sequence consisting: of thick, generally massive sandstone units, laterally impersistent and often wedge or channel shaped in form. Note the absence of any major siltstone developments.
- C. General appearance of the Quarryhill Sandstones at Quarryhill.
Overall, majority of the sandstones appear massive, although thick siltstones do break up the sequence in contrast to the Kildrummy Castle exposures. (a pale very-fine sandstone / siltstone is just visible in the bottom left of the view).



a



b



c

Plate 2.3 Thin sections of lavas from within the Rhynie Group
sequence.

- A. General form of the lava from the Glen of Cults showing abundant large vesicles, and large feldspar phenocrysts. (field width 10 mm)

- B. Large, but weathered, feldspar phenocrysts from the lava flows of the Glen of Cults. (field width 3mm)

- C. Thin section of the Gartly variety of lava, note that no vesicles are present, and only a few 'corroded' phenocrysts are evident. (field width 1.5 mm)

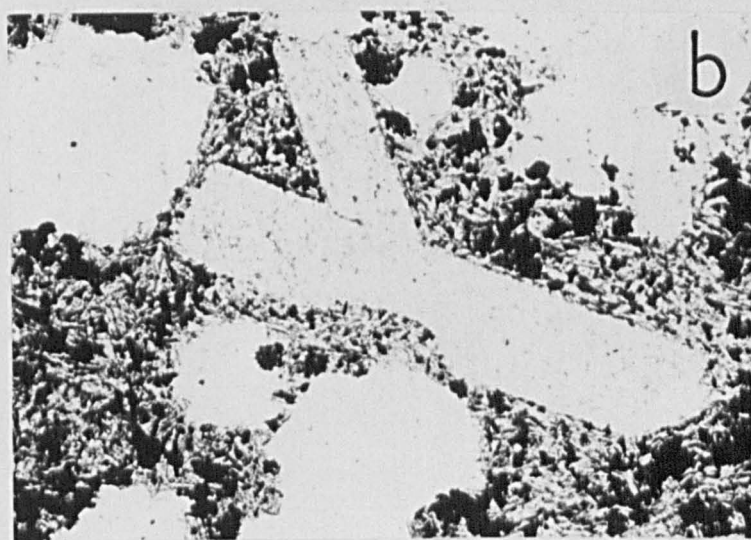
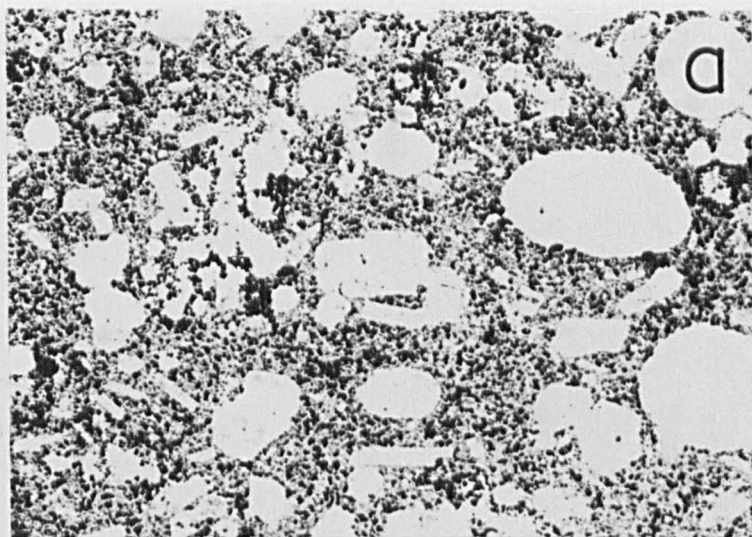
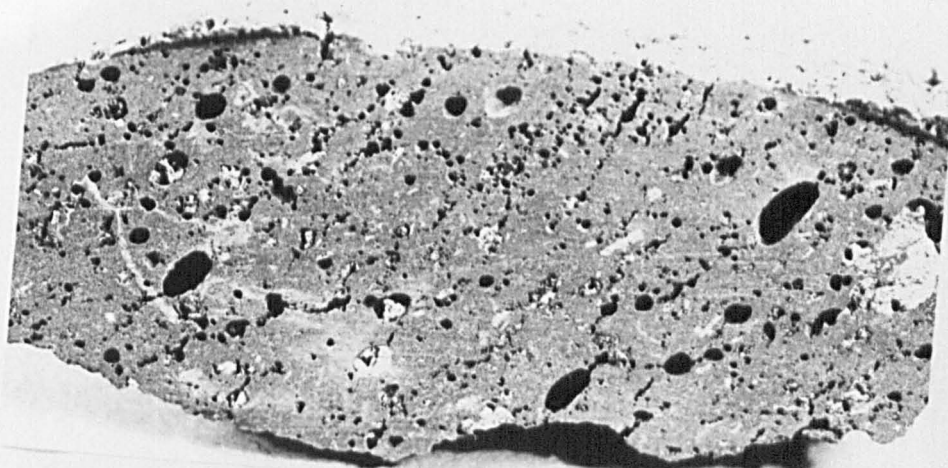


Plate 2.4 Hand specimens of the lavas from the lower part
of the Rhynie Group sequence.

A, B Samples of the 'Cork Rock' from the Glen of Cults showing abundant gas vesicles and highly weathered feldspar phenocrysts. Note the apparent 'stretching' of some vesicles. (scale: natural size)

C. Sample of lava from Gartly.
Although only one lava flow (possibly two) is recognised, the Gartly variety differs greatly from the nearby Glen of Cults varieties in that no vesicles are present, and feldspar phenocrysts are small and insignificant.
(scale: natural size)



a



b



c

Plate 2.5 Photomicrographs of the Rhynie Chert.

The adjacent series of photomicrographs are intended to demonstrate the excellent preservation of organic material within the cherts, both in fine detail, and in an original undistorted state.

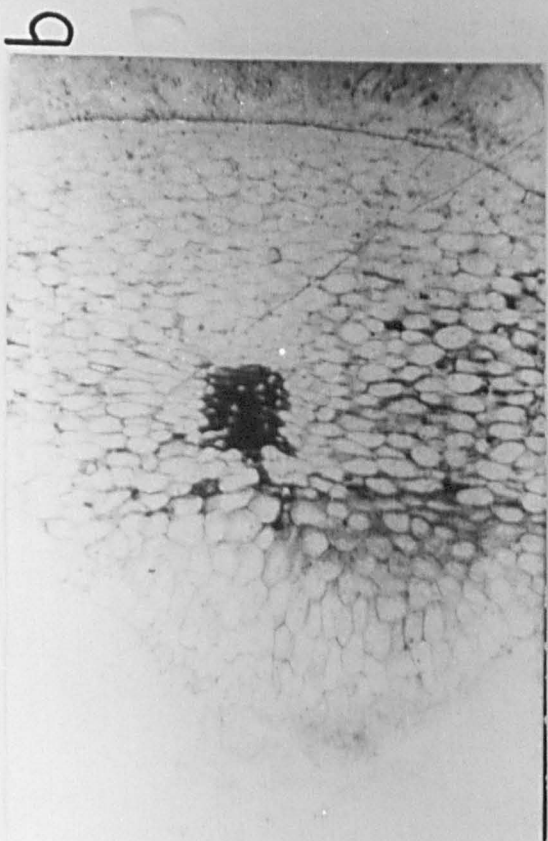
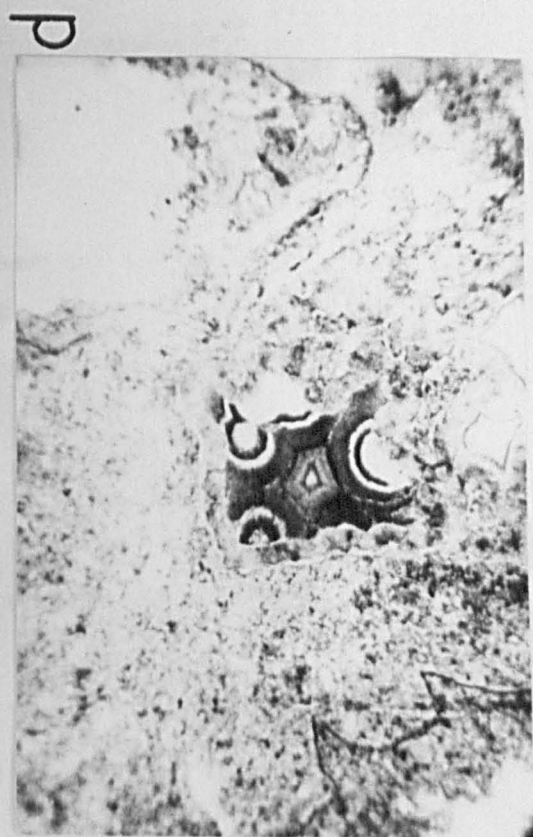
Plates A, B, and C demonstrate the above features, and in particular, plate B shows the excellent preservation of cell structure by the chert.

Plate C shows the undistorted preservation of an individual sporangia containing several spores.

The chert itself is generally microcrystalline / cryptocrystalline and shows little structure.

Desiccation voids are a common feature, and plate D shows such a void infilled by opaline silica with concentric inclusion patterns.

(scale :	A -	field width	2mm)
("	B -	"	1mm)
("	C -	"	0.25mm)
("	D -	"	1mm)



CHAPTER 3

1. WESTERN COASTAL SECTION.

	MEGAFACIES	STRATIGRAPHY / SUBFACIES
	Alluvial Fan (A)	Upper Finton Conglomerate (A5)
	Lacustrine (D)	Finton Fish Bed (D1)
	Alluvial Fan (A)	Lower Finton Conglomerate (A3)
COASTLINE MEGAFACIES	Braided Stream / Wadi (B)	Castle Hill Sandstone (B2a)
	Piedmont Floodplain / Playa (C) (marginal)	West Harbour Formation (C3)
	Piedmont Floodplain / Playa (C)	East Harbour Formation (C1c)
FINING MEGAFACIES	Piedmont Floodplain / Playa (C) (marginal)	Grovie Sandstone (C2)
	Alluvial Fan (A)	Grovie Conglomerate (A2)

B EASTERN COASTAL SECTION

	MEGAFACIES	STRATIGRAPHY / SUBFACIES
FINING MEGAFACIES		
	Piedmont Floodplain / Playa (C)	New Aberdour Siltstone (C1b)
	Piedmont Floodplain / Playa (C) (marginal)	Dundarg Castle Sandstone (C4)
	Braided Stream / Wadi Wadi (B)	Dundarg Castle Conglomerate (B1)
	Alluvial Fan (A)	Flecker Meadow Conglomerate (A1)

C CENTRAL COASTAL SECTION

	MEGAFACIES	STRATIGRAPHY / SUBFACIES
FINING MEGAFACIES	Piedmont Floodplain / Playa (C)	
	Braided Stream / Wadi (B)	Pennan Sandstone (B2b)
		Pennan Conglomerate Sst (B1a)
		Need Haven Conglomerate (B3)
	Alluvial Fan (A)	Pennan Head Conglomerate (B1b)
		Quarry Conglomerate (E)

D QUARRYHEAD COASTAL SECTION

	MEGAFACIES	STRATIGRAPHY / SUBFACIES
FINING MEGAFACIES	Piedmont Floodplain / Playa (C)	
	Piedmont Floodplain / Playa (C) (marginal)	
	Braided Stream / Wadi (B)	
	Alluvial Fan (A)	Quarryhead Conglomerate (A1) (interdigitates with floodplain facies)

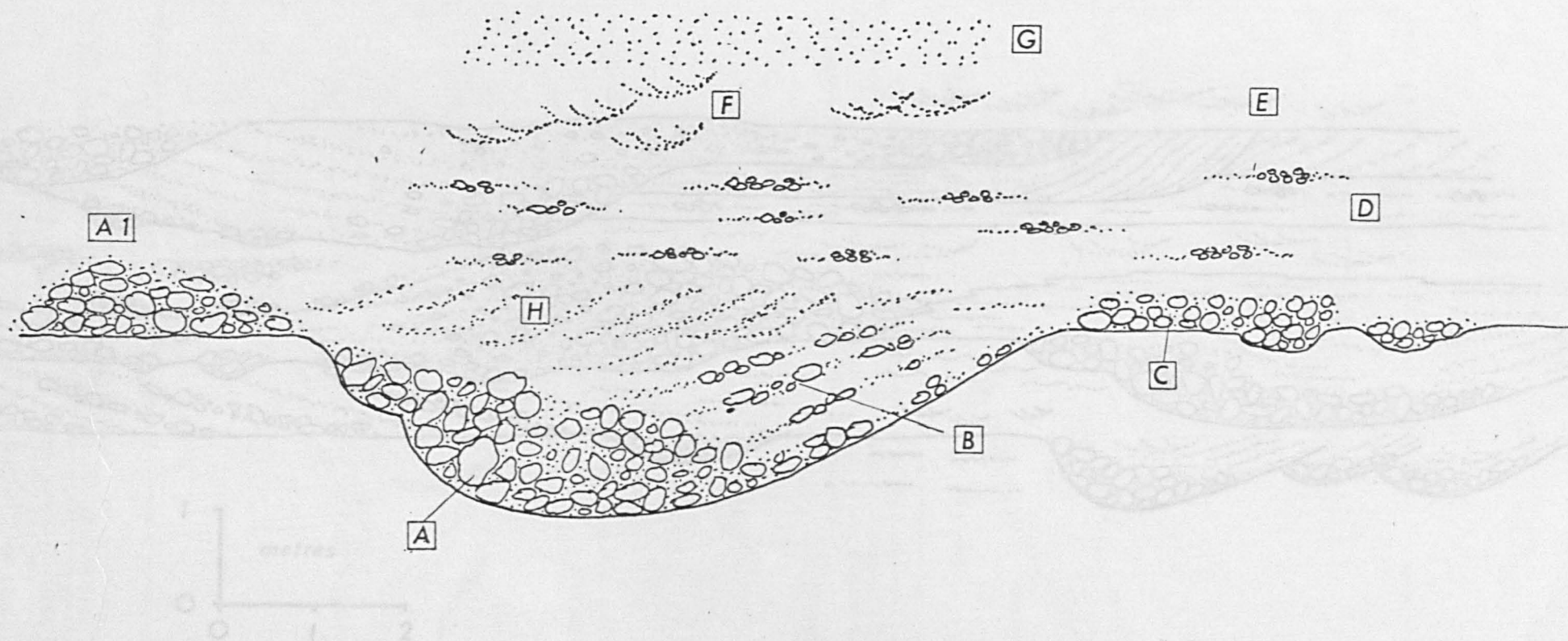


Figure 3.3 Generalised reconstruction of lithofacies relationships within subfacies B1.

Figure 3.4 Detailed vertical and lateral field log from within subfacies B1.

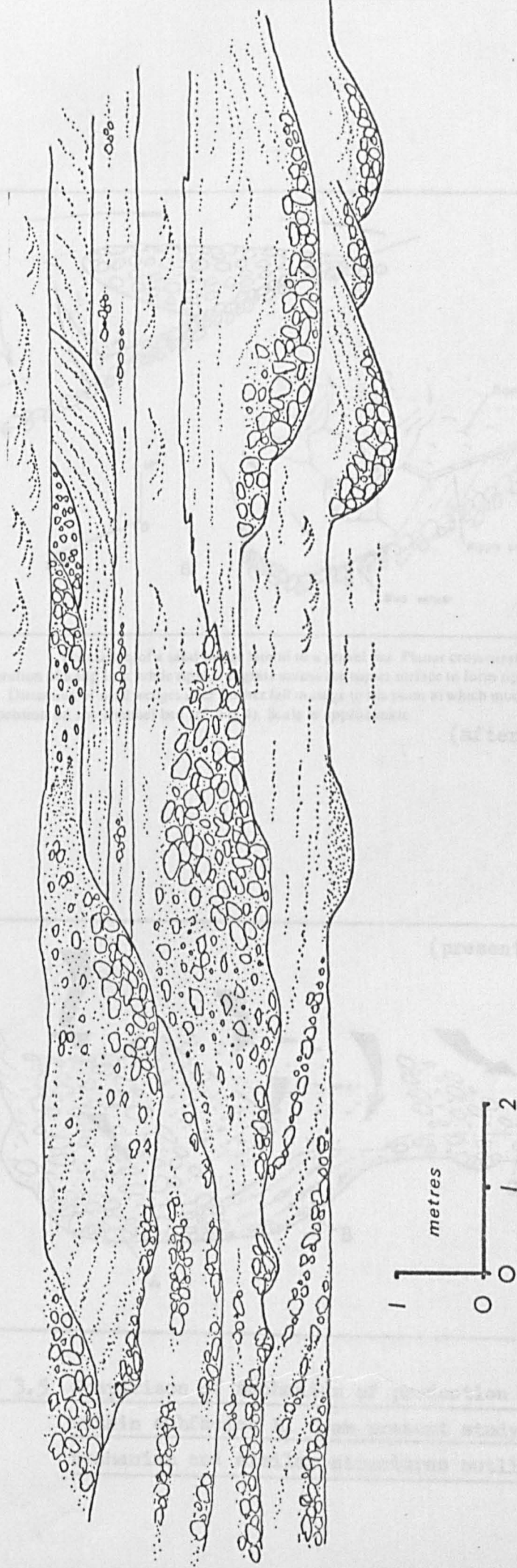
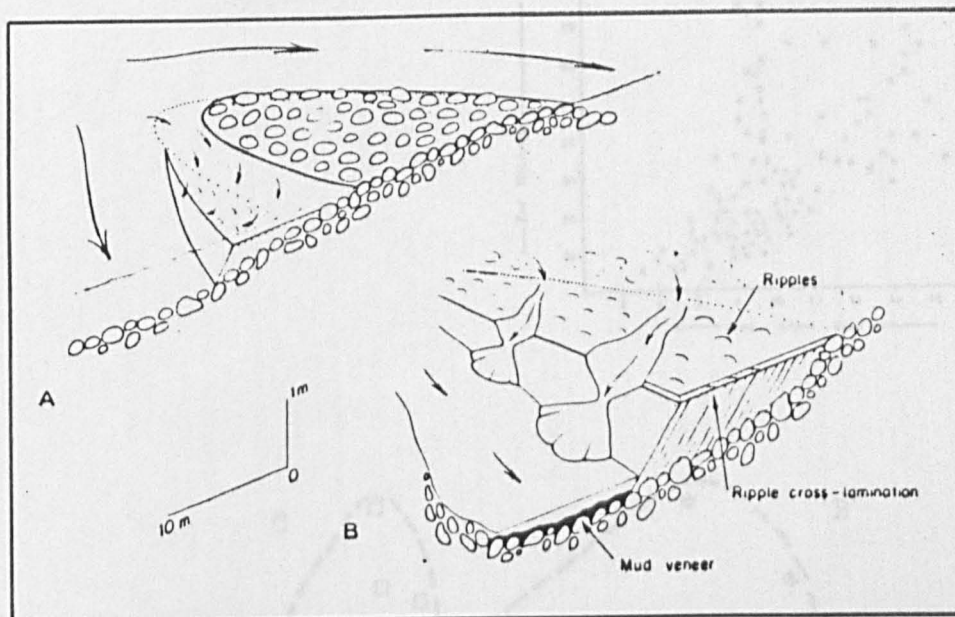


Figure 3.4 Detailed vertical and lateral field log from within subfacies B1.



Formation of a sand wedge lateral to a gravel bar. Planar cross-strata form by outward migration of a slip face, while ripples migrate across the topset surface to form ripple cross-lamination. B. Dissection of sand wedges after further fall in stage to the point at which mud starts to settle from suspension on the channel bed (cf. Fig.4). Scale is approximate.

(after Rust 1972)

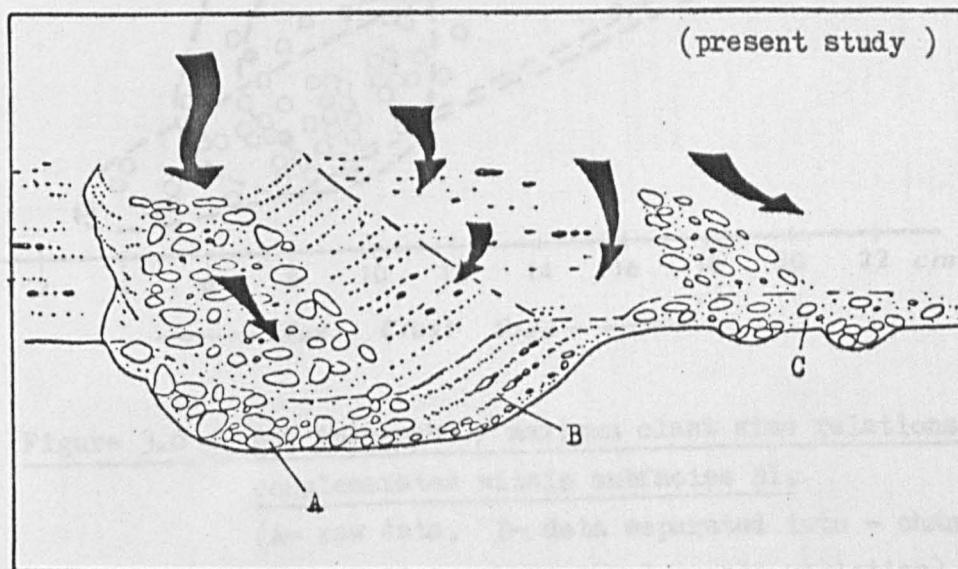


Figure 3.5 Comparison of mechanism of production of lithofacies within subfacies B1 from present study with a similar mechanism and similar structures outlined by Rust (1972).

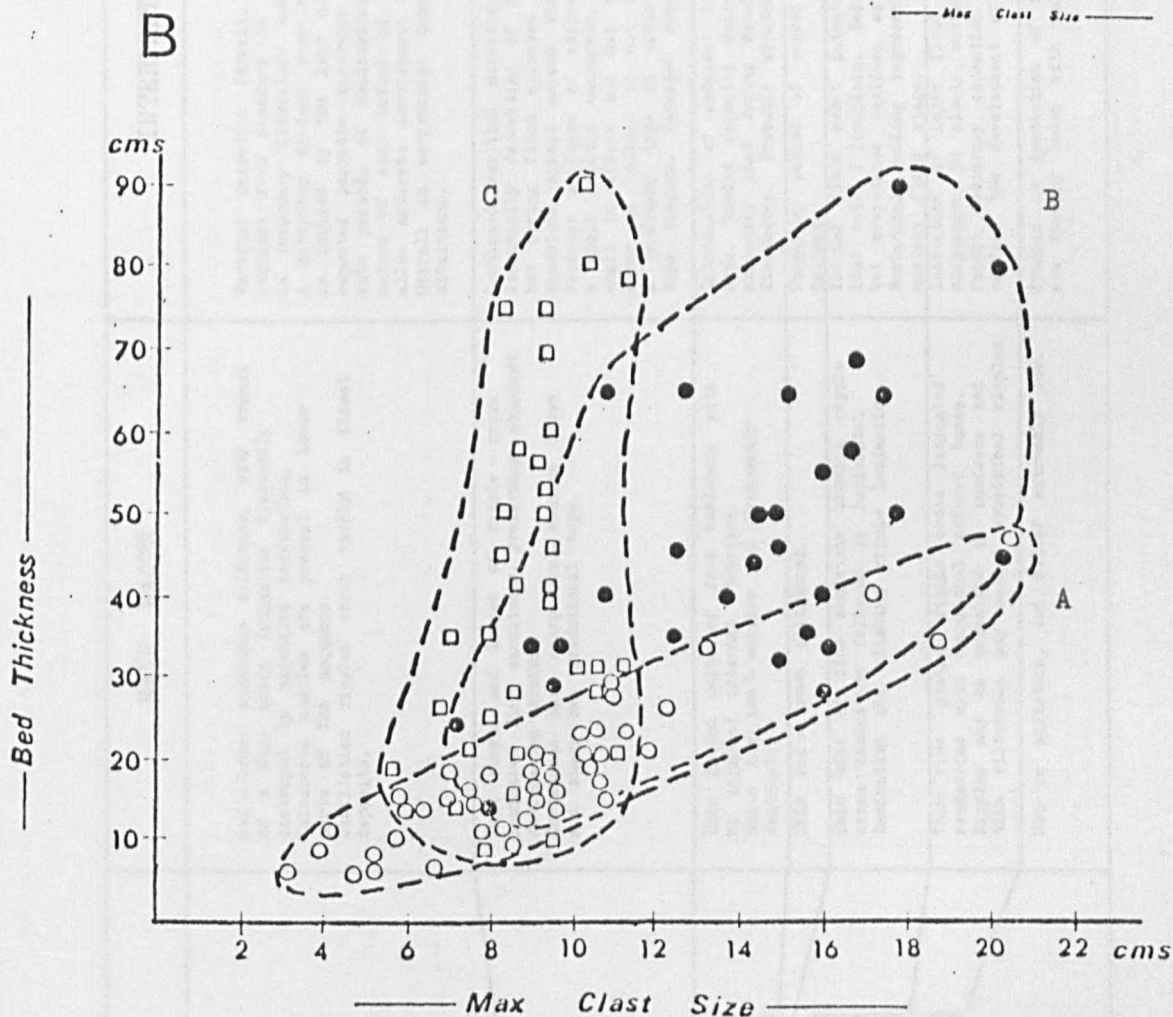
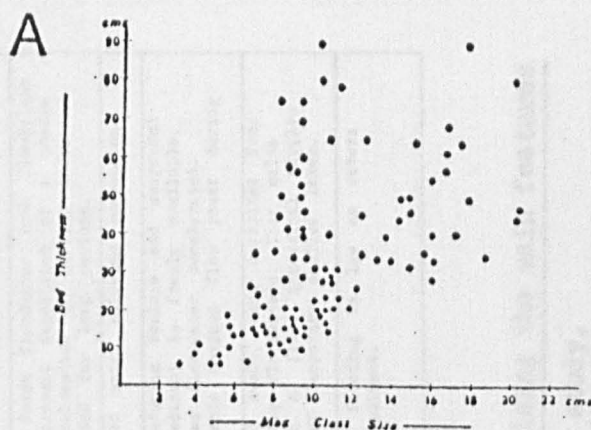


Figure 3.6 Bed thickness / maximum clast size relationships for conglomerates within subfacies Bl.

(A- raw data, B- data separated into - channel, single and multiple sheet conglomerate varieties).

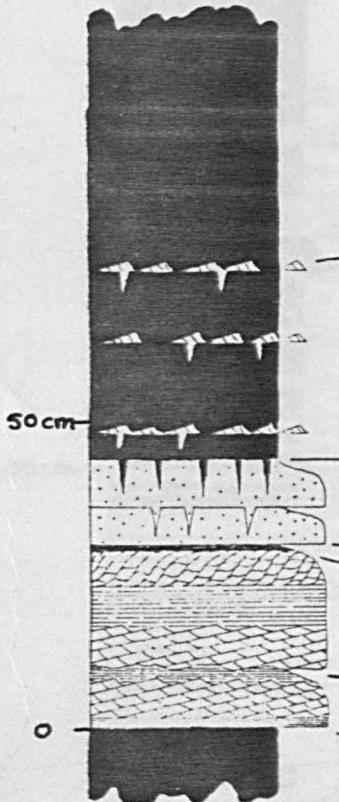
	MAIN FACTS	INTERPRETATION
	Red - brown micaceous siltstone, with traces of a fine muddy lamination frequently destroyed by extensive desiccation. Calcareous nodules are present in lower parts of the sequence. Oscillation ripples occur rarely in finest deposits.	Vertical accretion deposit. Deposition of suspended sediment from standing or slowly moving floodwaters in temporary floodplain lakes. A situation distant from a main distributary channel is implied by the lack of coarse detritus, and the repeated periodic incursion of floodwater alternating with periods of desiccation confirms the ephemeral nature of such bodies of water. Soil forming processes allow calcareous development in more marginal sites. Overall an environment comparable to some backswamp situations.
	Thin sheets and lenses of ripple - cross laminated fine sandstones preserving abundant desiccation cracks. Sandstones have sharp non - erosive bases and sharp non gradational tops.	Continued vertical accretion on floodplain surface. Essentially deposition of fine suspended load material but during flood episodes sheets of ripple - bedded sandstone spread across the floodplain surface. Periodic influxes of sediment laden floodwater introduced a small bedload component, but flood episodes were small in effect and did not result in ponding of water as bedload is not followed by suspended load. A Backswamp type of situation with intercalated levee type tongues. Repeated exposure and desiccation.
	Thin graded units of fine sandstone with no apparent internal structure. Units are non - erosive and frequently desiccated.	Introduction of sediment laden floodwater into floodplain area. Graded deposits represent deposition of a coarse suspended load during deceleration of heavily laden floodwater. Probably exposed for long periods.
	Thin red - brown siltstones.	Temporary period of ponded water allowing suspension fallout.
	Thin unit of fine sandstone showing ripple cross lamination followed by horizontal lamination and climbing ripple lamination.	Initial flood event introducing bedload and suspended load onto floodplain. Sediment is freely available, but competence declines as floodwater decelerates. Horizontal bedding represents maximum flow power during maximum flood stage.
	Thin fine grained ripple cross laminated sandstones with occasional scoured bases. Ripples may be preserved on surfaces and thin siltstones may record symmetrical ripples.	Initiation of major flood event, sand deposited from suspension in slowly moving floodwaters. Thin silts record temporary cessation of flow, symmetrical ripples confirm the development of temporary shallow lakes.
	Cut on siltstone, but relief extremely low.	Erosion at initiation of flooding is low as waters are heavily laden with sediment.

Figure 3.7 Lithoprobe selected from subfacies Cla (Crovie Siltstone) summarising the main features and outlining the sedimentological interpretation from the present study.

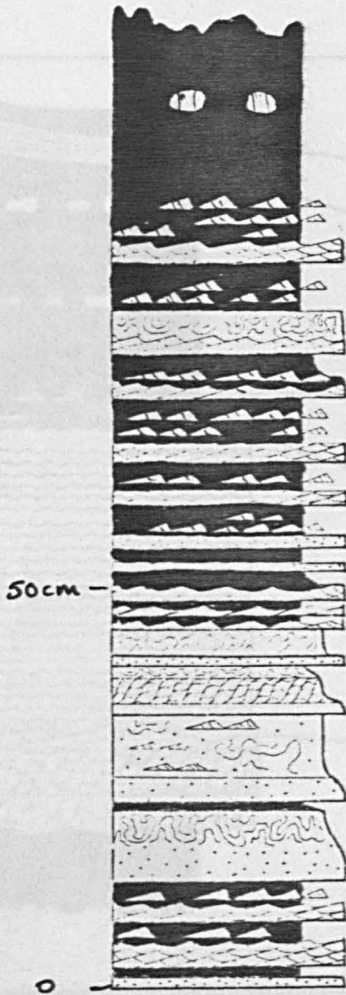
	MAIN FACTS	INTERPRETATION
	Thick units of brown and grey siltstone generally massive, but may show a fine muddy lamination. Units are frequently desiccated, and commonly have layers of large calcareous nodules.	Vertical accretion of suspended sediment load in sites distant from a main distributary point. Sediment represents suspension fallout of silts from distributary floods forming temporary floodplain lakes. Desiccation cracks confirm the transitory nature of these lakes in recording repeated periods of emergence and submergence of the floodplain surface. At times the floodplain appears to have been stable enough to allow calcrete development.
	Relatively thin units of fine sandstone showing a range of structures ranging from graded bedding to ripple lamination and convolute bedding. Sandstones are interbedded with thin siltstones, and often occur desiccated, as a couplet. Thin lenses or flasers of sand occur within the siltstones.	Deposition of suspended and small bedload components in proximal portions of small temporary Piedmont plain lakes. Flood events appear to be numerous, but quite small although graded beds and convolute bedding suggest that at times sedimentation was probably rapid. The sediments are in many ways comparable to some undivided topstratum and more distal levee type deposits. Frequent ability of floodwater to rework small amounts of bedload into lenses suggests minor ripple development in slowly moving, not stationary floodwaters.
	Thicker units of fine sandstone, most commonly massive or showing poorly developed ripple lamination. Graded units are common and often associated with convolute lamination. Climbing ripple lamination is present but rare.	Thicker sediment units possibly record larger or more proximal sites of deposition. Overall the sediments indicate frequent and often heavily laden floodwaters being introduced onto the floodplain area. Small temporary lakes may have developed, but are not as common or well developed as in higher portions. Lakes were probably shallow and mostly very impersistent. Closely comparable to some levee deposits.
	Thin units of ripple laminated sandstone interbedded, not directly related to thin siltstones. May be desiccated individually or as a couplet.	Minor flood events causing small splays of ripple bedded sandstone to migrate across small portions of the floodplain area in shallow slowly moving and rapidly diminishing floodwaters. Closely comparable to some levee deposits.

Figure 3.8 Lithoprofile from subfacies Clb (New Aberdour Siltstone) summarising the main features and outlining the sedimentological interpretation from the present study.

	MAIN FACTS	INTERPRETATION
	Red mudstone, often desiccated and occasionally preserving symmetrical ripples.	Deposition of suspended load in ponded water, subsequent exposure and desiccation. Last remnants of flood event.
	Mudstone with fine lamination, desiccated rarely	Suspension fallout in ponded water. Further introduction of floodwater without significant coarse detritus causes fine lamination.
	Grey, grey - brown siltstones with a poorly developed muddy lamination. Frequently desiccated, and often displaying sheets of calcareous nodules.	Deposition of suspended load from temporary floodplain lakes, in ponded or slowly moving floodwaters. Desiccation confirms the ephemeral nature of these lakes. Long stable periods allow development of calcrete nodules. Comparable to some Backswamp environments.
	Thin impersistent sheets and lenses of fine ripple laminated sandstone.	Re - working of coarse detritus following major flood period. Slowly moving floodwaters now only capable of transporting large amounts of suspended sediment.
	Thick units of thinly interbedded fine sandstone, very fine sandstone, and siltstone. Poorly developed ripple bedding imparts a wavy bedded appearance to the deposits.	Deposition of coarsest sediment shortly after the introduction of heavily laden floodwater onto the floodplain area. Mixed grainsize range suggests that the unit records either repeated flood events or repeated flood surges during one major flood episode. Deposit is analogous to some proximal floodplain deposits, for example, levee and undivided topstratum deposits. Deposition occurs in shallow water close to dispersion point.
	A relatively thin unit of sandstone showing an initial, often coarse, intraformational conglomerate or massive medium grained sandstone. Climbing ripple laminated fine sandstone often follows, eventually replaced by ripple laminated sandstones.	Floodwater rapidly introduced onto floodplain surface, limited scouring occurs due to high suspended load, but large clasts record magnitude of flood causing destruction of floodplain surface. Overlying deposits record the rapid deceleration of the floodwaters, and rapid deposition of coarse bedload in rapidly shoaling waters. Environment comparable to proximal levee environment.

Figure 3.9 Lithoprofiles from subfacies Clc (East Harbour Formation) summarising the main features and outlining the sedimentological interpretation from the present study.

Figure 3.10 A. Sedimentation trends within the New Aberdour
Siltstone Formation (subfacies Clb).

Figure 3.10 B. Relationship between coarse and fine member thickness
for cycles within subfacies Clb.

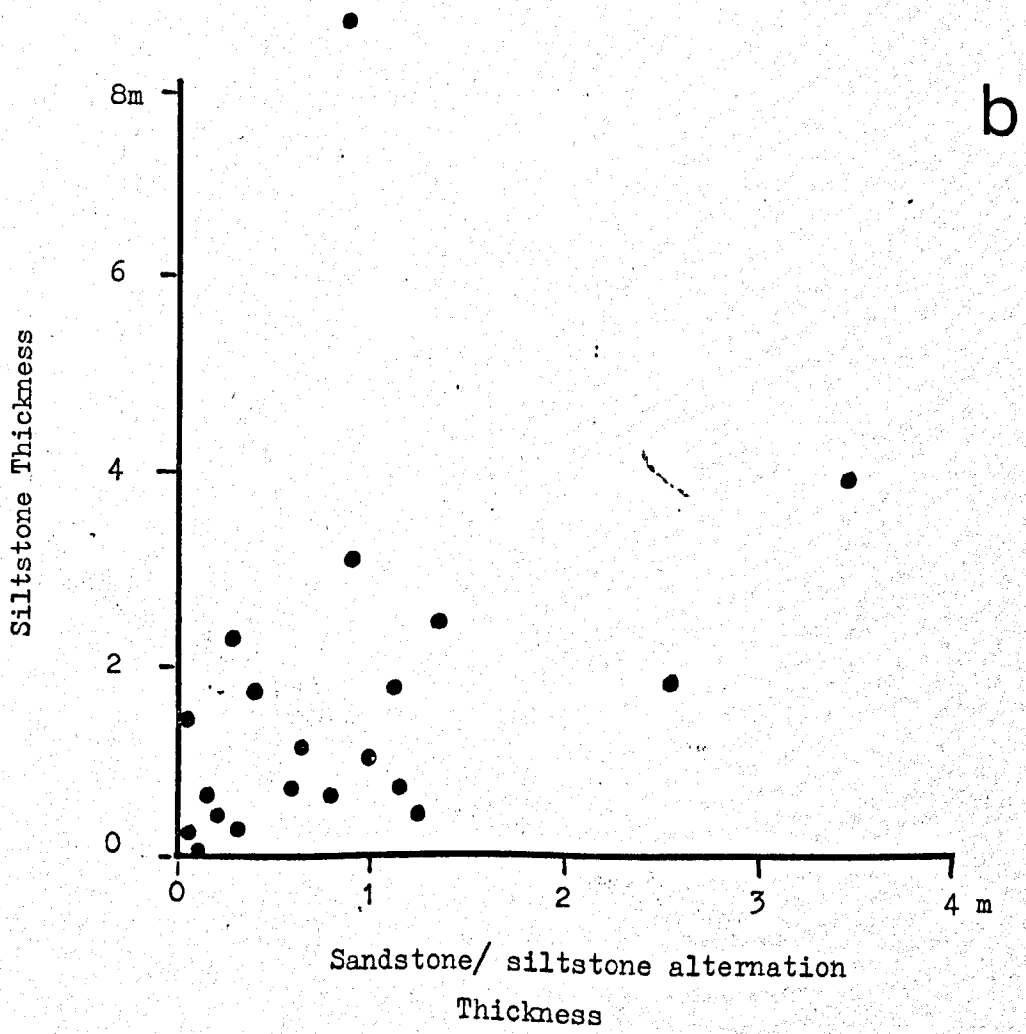
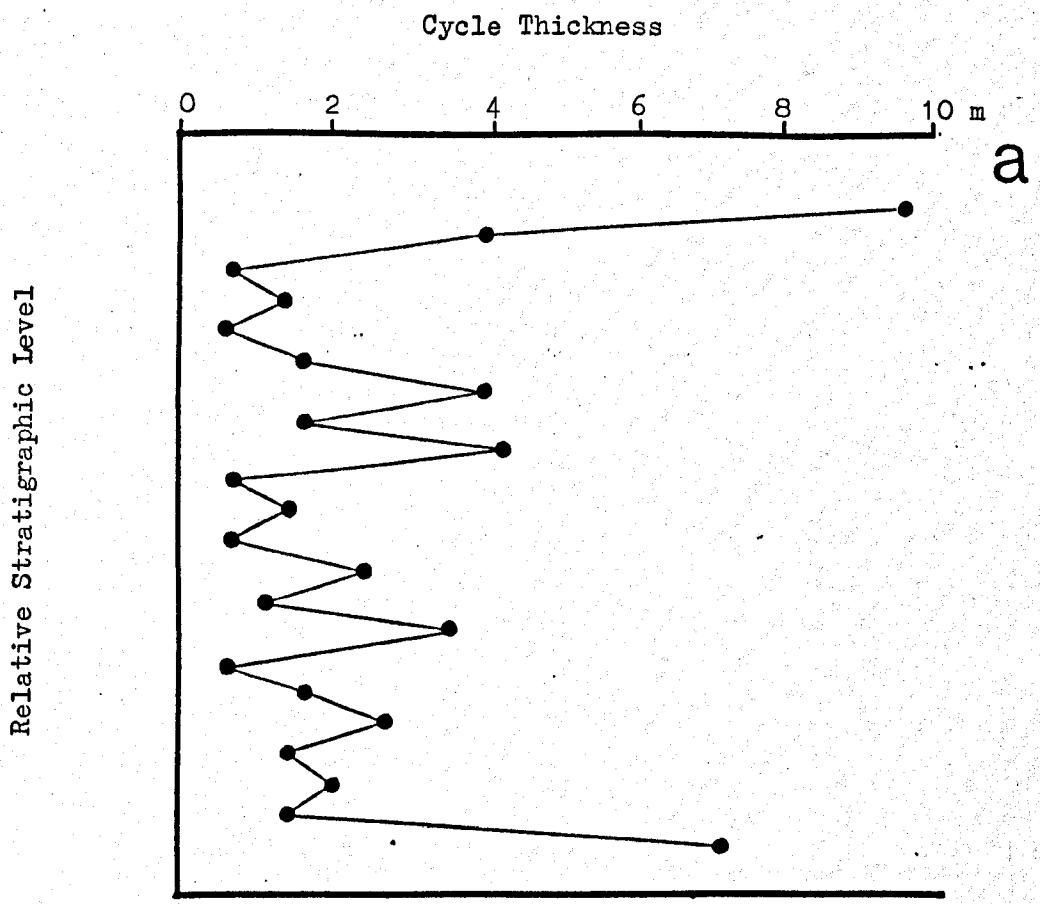


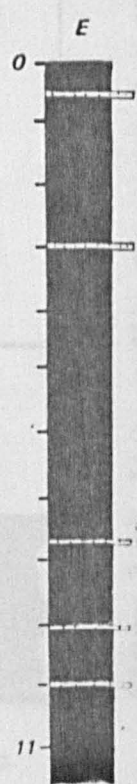
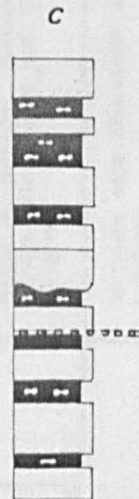
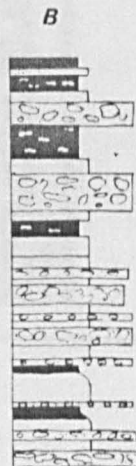
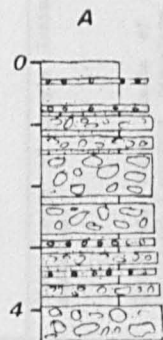
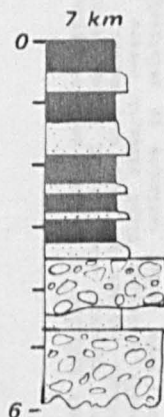
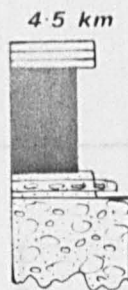
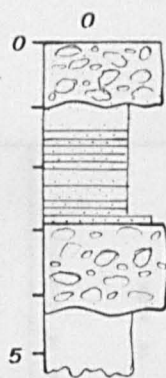
Figure 3.11 Comparison between logged sections from the present study, and sections provided by Williams (1970) from the Biskra region of north Africa.

The upper two sections are from Williams (op cit) and show logged profiles at increasing distances from the alluvial fan.

The lowermost sections are from the Gamrie Outlier

- A - subfacies A2 (Crovie Conglomerate Formation).
- B - subfacies C2 (lower portion of the Crovie Sandstone Formation).
- C - subfacies C2 (upper portion of the Crovie Sandstone Formation).
- D - subfacies Cla (lowermost portion of the Crovie Siltstone Formation).
- E - subfacies Cla (uppermost portion of the Crovie Siltstone Formation).

(all depths indicated are in metres).



	MAIN FACTS	INTERPRETATION.
	Thick brown coarse siltstone generally massive but with rare mud laminae. Abundant desiccation. Densely packed calcareous nodules common.	Deposited during suspension fallout from slow moving or occasionally ponded floodwaters. Intense desiccation confirms repeated exposure of floodplain surface. Development of calcareous nodules suggests fluctuating groundwater table and development of calcareous soil profiles.
	Thin sheets of ripple cross laminated sandstone interbedded with brown siltstones.	Floodplain topstratum deposits sharply overlie abandoned channel. Temporary movement of bedload sediment via a dominant suspended load.
	Channel infill comprised of cross stratified sandstones overlying a gentle erosion surface, capped by flat bedded sandstones.	Infilling and choking of an ephemeral stream channel crossing the floodplain surface. Initial violent flood allowed transport of bedload as subaqueous dunes. Later deposits record declining flow power as flood decreases and depth shoals.
	Thin sheets of ripple laminated sandstone.	Cycle eventually grades into more distal type of floodplain deposit.
	Relatively thick sheets of fine ripple laminated / massive sandstone, generally non erosive bases.	Floodplain topstratum deposits formed adjacent to main channels. Deposits are essentially levee
	Underlying sandstone unit grades into thick siltstone with isolated lenses of sandstone. Calcareous nodules in higher parts.	Floodplain topstratum deposits as above. Deposition of fine sediment from suspension on floodplain following channel deposition without a break.
	Gentle erosion surface, followed by cross stratified sandstones with occasional mud drapes on foresets. Sandstone grades rapidly into rippled and flat bedded sandstone.	Channel infilled by bedload sediment transport as subaqueous dunes. Temporary cessation of bedload transport allowed suspension fallout to drape over dunes. Gradually declining flood strength covers dunes with mixed ripple / flat bedded sediments in relatively shallow water.
	Siltstone with thin sheets and lenses of sandstone. Flat bedded sandstone followed by cross stratified sandstone, rapidly followed by ripple laminated sandstone. Distinct stepped erosion surface overlain by cross stratified gravel and fine conglomerate.	Deposition of suspended load on floodplain surface. Minor movement of bedload component. Channel infill in a more proximal location. Stepped erosion surface confirms reactivation of channel. Powerful floods transport coarsest debris from nearby alluvial fan. Channel eventually choked by bedload sediment moved as subaqueous dunes.

Figure 3.12 Lithoprobe from subfacies C2, showing sedimentological interpretation,

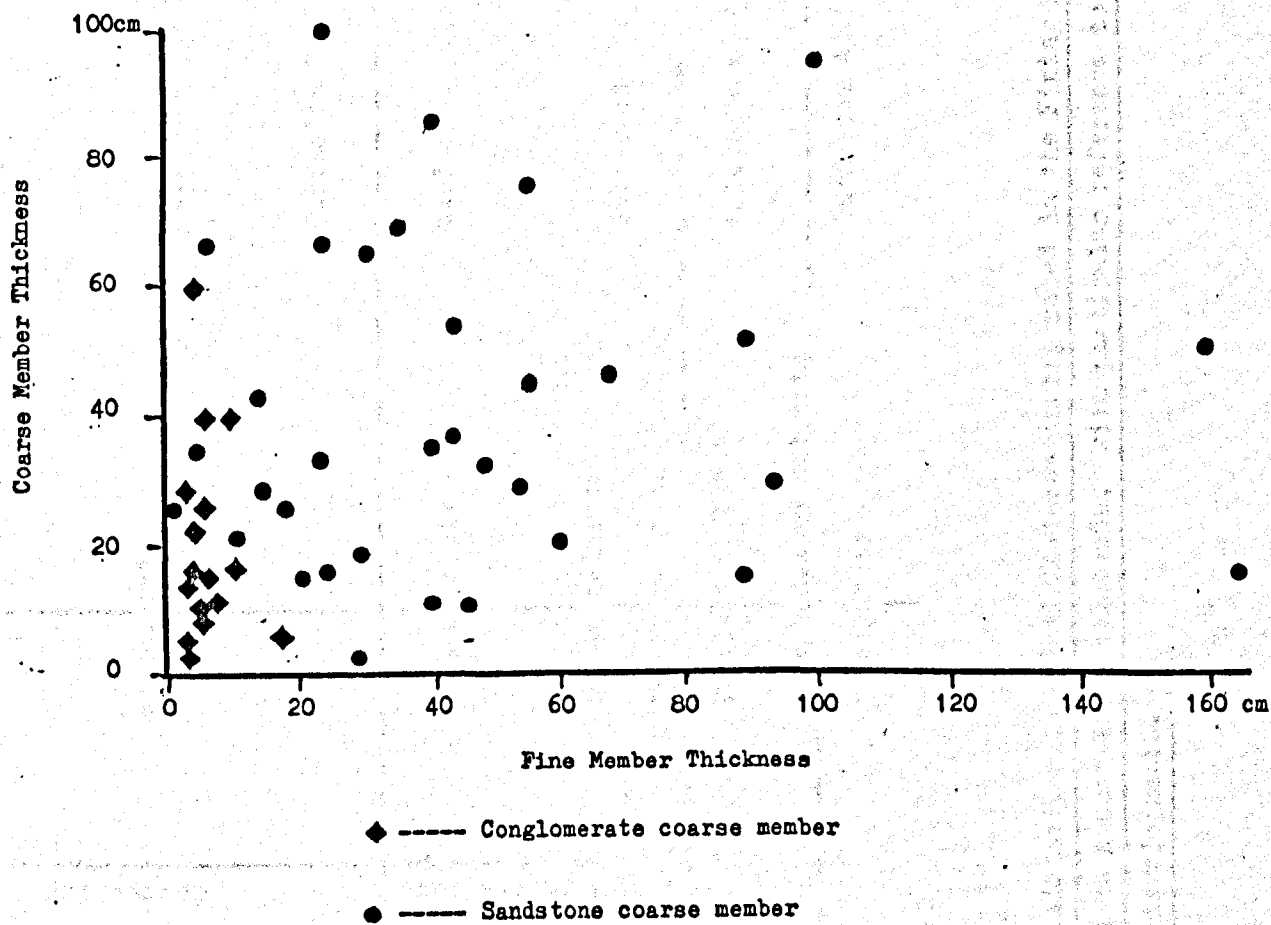


Figure 3.13 Comparison of coarse and fine unit thicknesses from cycles within subfacies C2 (Crovie Sandstone).

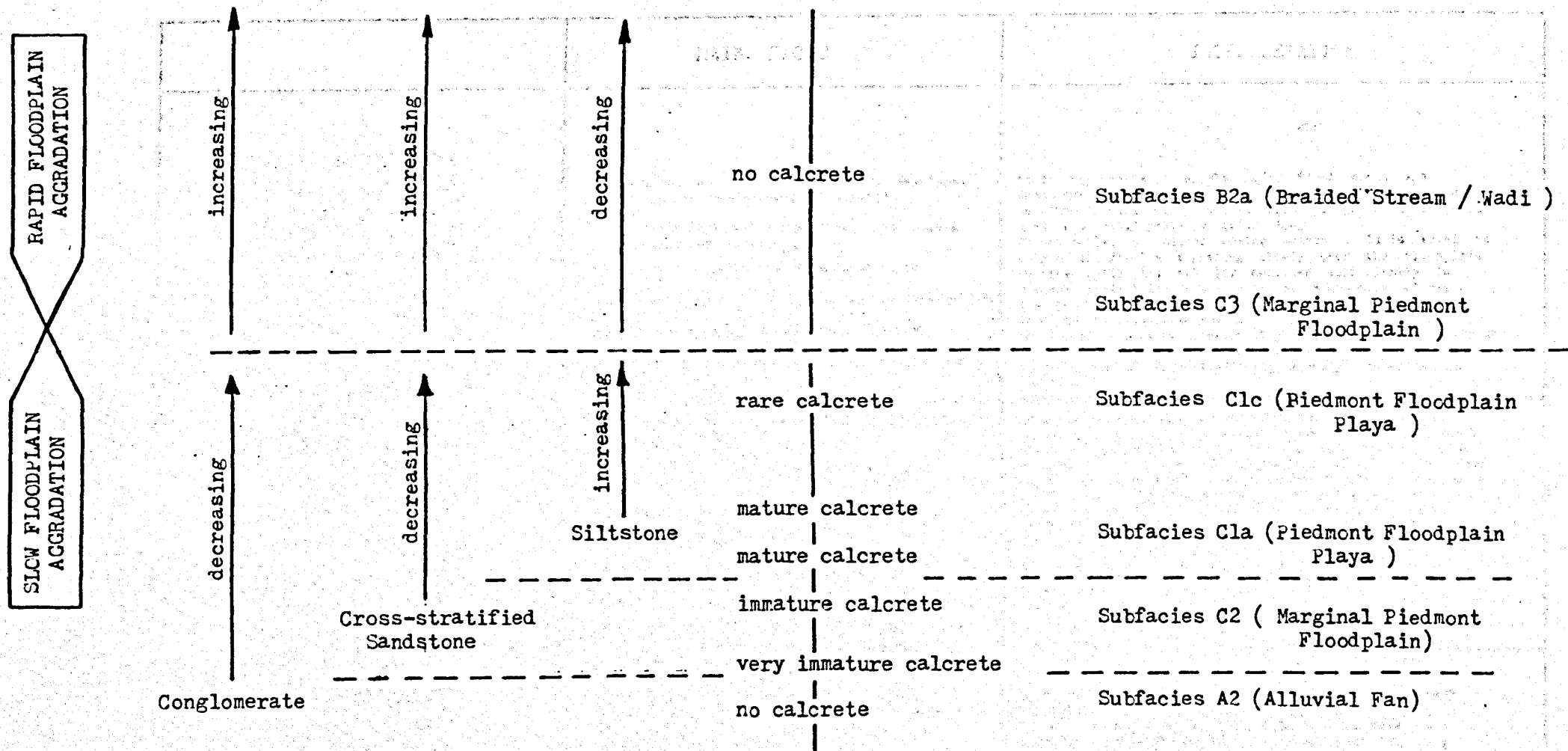


Figure 3.14 Summary of main sedimentological features incorporated in the Fining Megacycle, and its reversal to a Coarsening Megacycle, with particular reference to the importance of calcrete developments.

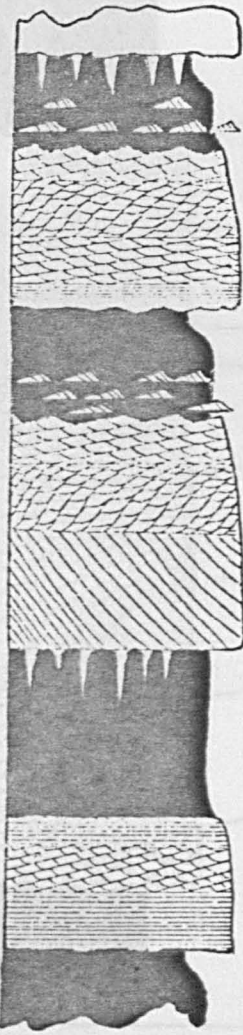
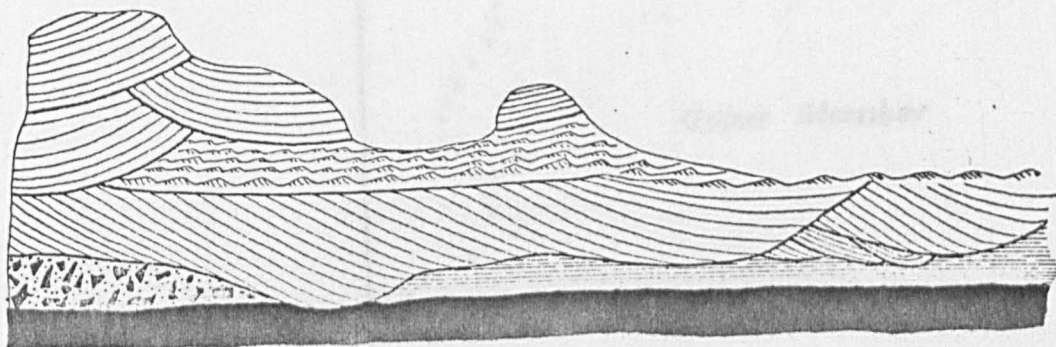
	MAIN FACTS	INTERPRETATION
	Red - brown mudstone with commonly developed silty graded lamination. Desiccated Brown micaceous siltstone with thin sheets and lenses of sandstone. Ripple cross laminated fine sandstones Fine sandstone with climbing ripple lamination. Ripple cross laminated fine sandstones Flat bedded micaceous sandstone, slight erosion	Cycle represents a single major flood event and demonstrates the production of flat bedded sandstones in the initial high powered flood stage when sediment load was still probably quite low. Subsequently, in slower moving waters sand is moved as sheets of ripples migrating slowly over the floodplain surface until the velocity declines sufficiently to prevent sand being transported in suspension allowing the development of climbing ripples. Sand is finally reworked and further deposited in sheets of migrating ripples in slowly moving floodwaters. Eventually silt and mud are deposited out of suspension, with pulses of flow developing a silty lamination in these muds
	Brown micaceous sandstone with discontinuous sandstone lenses Ripple cross laminated fine sandstone Fine sandstone with climbing ripple cross lamination Fine sandstone with steep planar cross stratification Sharp non erosive junction	Cycle represents the introduction of heavily laden floodwater into already ponded water. Avalanche front cross stratification builds out in delta fashion into deeper water, while the concomitant reduction in water depth causes generation of climbing ripple lamination as floodwater is decelerated. Eventually ripple lamination forms under low flow powers and small sediment load prior to deposition of siltstone from out of suspension in slowly moving floodwaters. The cycle is analogous to a crevasse or fluvial delta play.
	Thick brown micaceous siltstone with frequent desiccation of top surface only. Horizontally bedded fine sandstone Ripple cross laminated fine sandstone. Flat bedded fine micaceous sandstone. Slightly erosive surface.	Cycle represents the rapid introduction of powerful floodwaters onto the floodplain surface. As flow power declines ripple lamination develops suggesting perhaps increased sediment load following the initial flood event or perhaps deeper floodwater. Eventually finer sediments are deposited from out of suspension in ponded or very slowly moving floodwater.

Figure 3.15 Lithoprobe from subfacies C3 (lower member of the West Harbour Formation) showing the main features and outlining the sedimentology from the present study.

	MAIN FACTS	INTERPRETATION
	Red mudstones showing abundant desiccation and occasional invertebrate trails - otherwise massive.	Deposition of finest sediment purely from suspension in ponded water on the floodplain surface. Such bodies of water were frequently replaced by strongly oxidising subaerial conditions.
	Sharp junction often preserving asymmetric ripples, and frequently showing abundant small scale burrows.	Cessation of bedload transport of coarse detritus due to stilling of floodwaters on floodplain surface. Preservation of low energy bedforms, and rapid establishment of simple fauna.
	Ripple cross laminated fine sandstone.	Infilling of small channels by bedload sediment.
	Broad channel erosion surface.	Minor channel distributing sediment onto floodplain.
	Fine sandstone with flat parallel bedding.	Vertical accretion of sediment in minor channel, channel chokes eventually but still retains ponded water allowing fallout of suspended load.
	Massive red mudstone.	Temporary development of small floodplain lake.
	Mixed ripple and climbing ripple laminated fine micaceous sandstones.	Levee type vertical accretion deposits formed marginal to channel developed due to avulsion of underlying channel.
	Gentle erosion plain, broad channel form. Flat bedded sandstones with patches of ripple lamination mostly near margins of channel shaped body.	Mixed deposition of suspended and bedload sediment within an active distributary channel transporting sediment onto floodplain surface. Sediment accretes vertically within channel eventually choking and causing migration by avulsion. An ephemeral stream channel.
	Deep erosion surface cut into previous floodplain sediments. Broad channel form.	Deposition of suspended and bedload sediment in broad channels or at the margins of such channels.
	Cross stratified fine sandstone.	
	Gentle erosive plane. Broad channel form.	Comparable to mixed crevasse splay and levee type deposits.
	Ripple cross laminated fine sandstone.	
	Thick intraformational conglomerate composed of large fragments of red mudstone.	Destruction and redeposition of cohesive floodplain material during initial violent flood episode.
	Low relief erosion surface cut into previous red mudstones.	

Figure 3.16 Lithoprobe profile from subfacies C3 (upper West Harbour Formation) showing the main features and outlining the sedimentological interpretation from the present study.

A



50cm

B

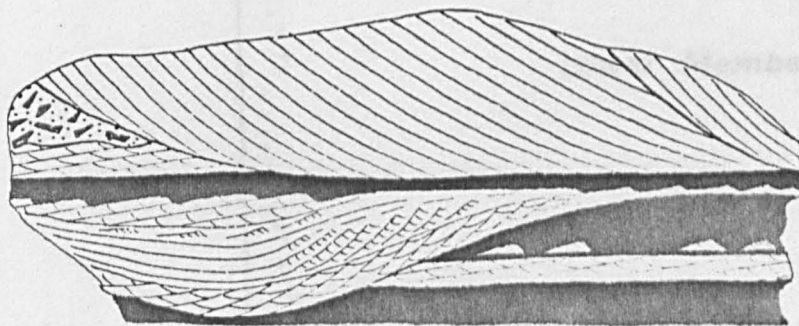


Figure 3.17 Field sketches of channelling and cross stratification
within the upper member of the West Harbour Formation.
(subfacies C3).

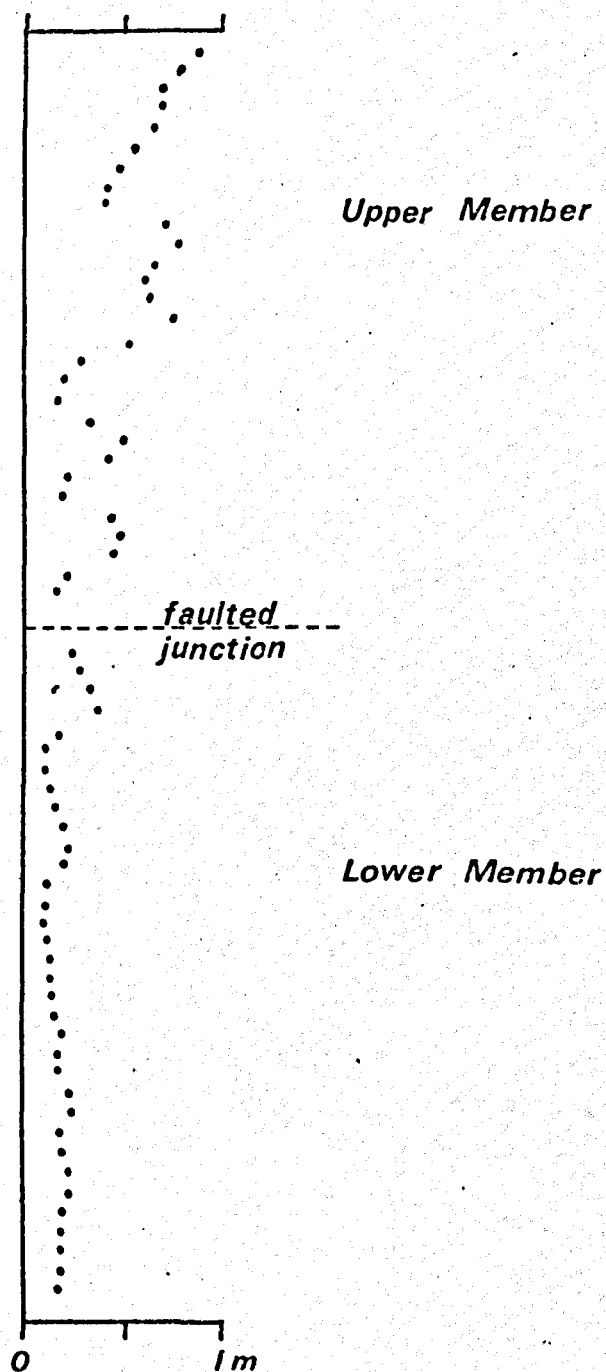
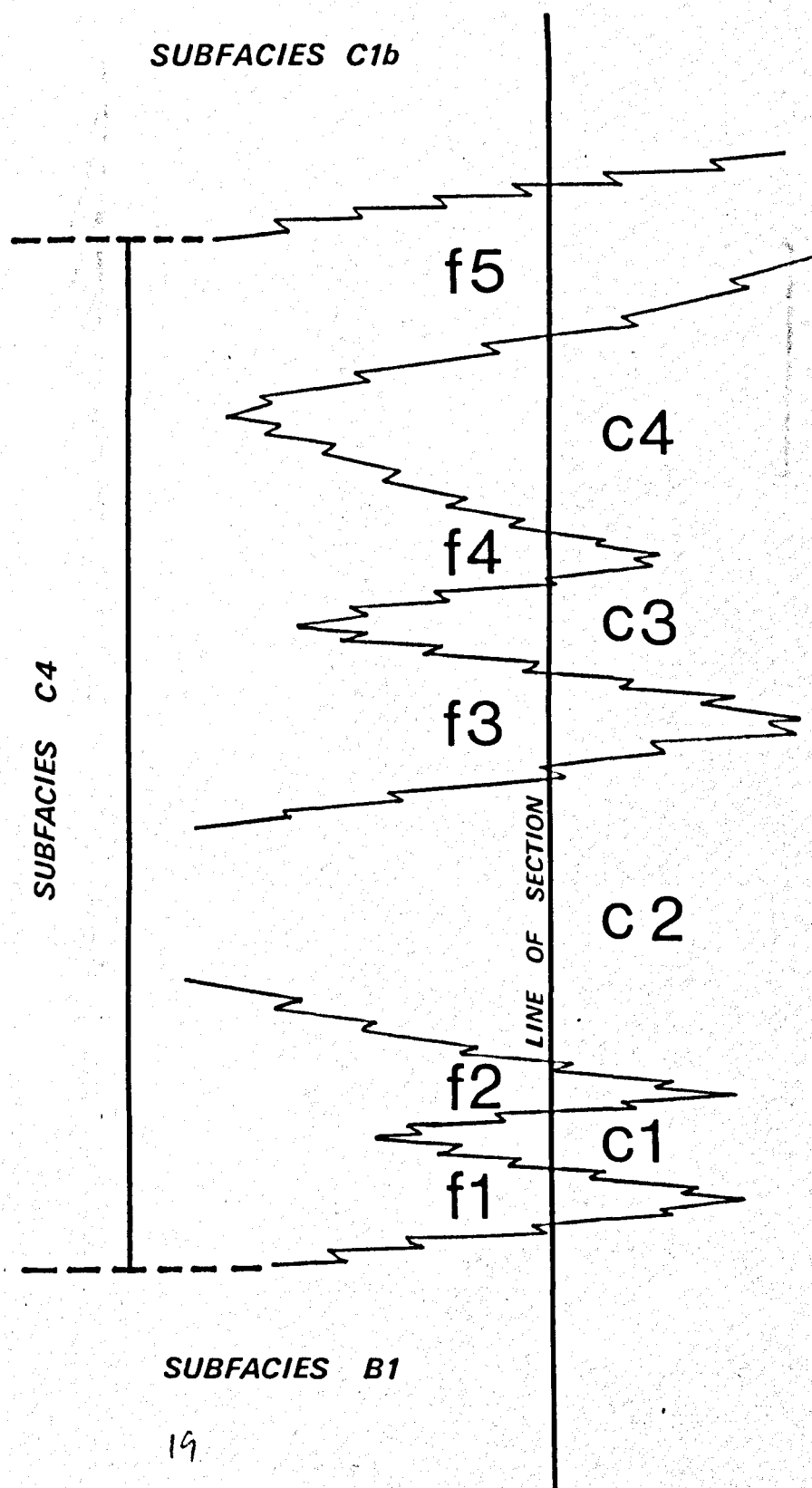


Figure 3.18 Sedimentation trends within the West Harbour Formation.
Graph shows smoothed time trend of sandstone thickness.



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Figure 3.19 Schematic reconstruction of subfacies C4 showing the interdigitation of coarse and fine members during the gradation of subfacies B1 into subfacies C1b.

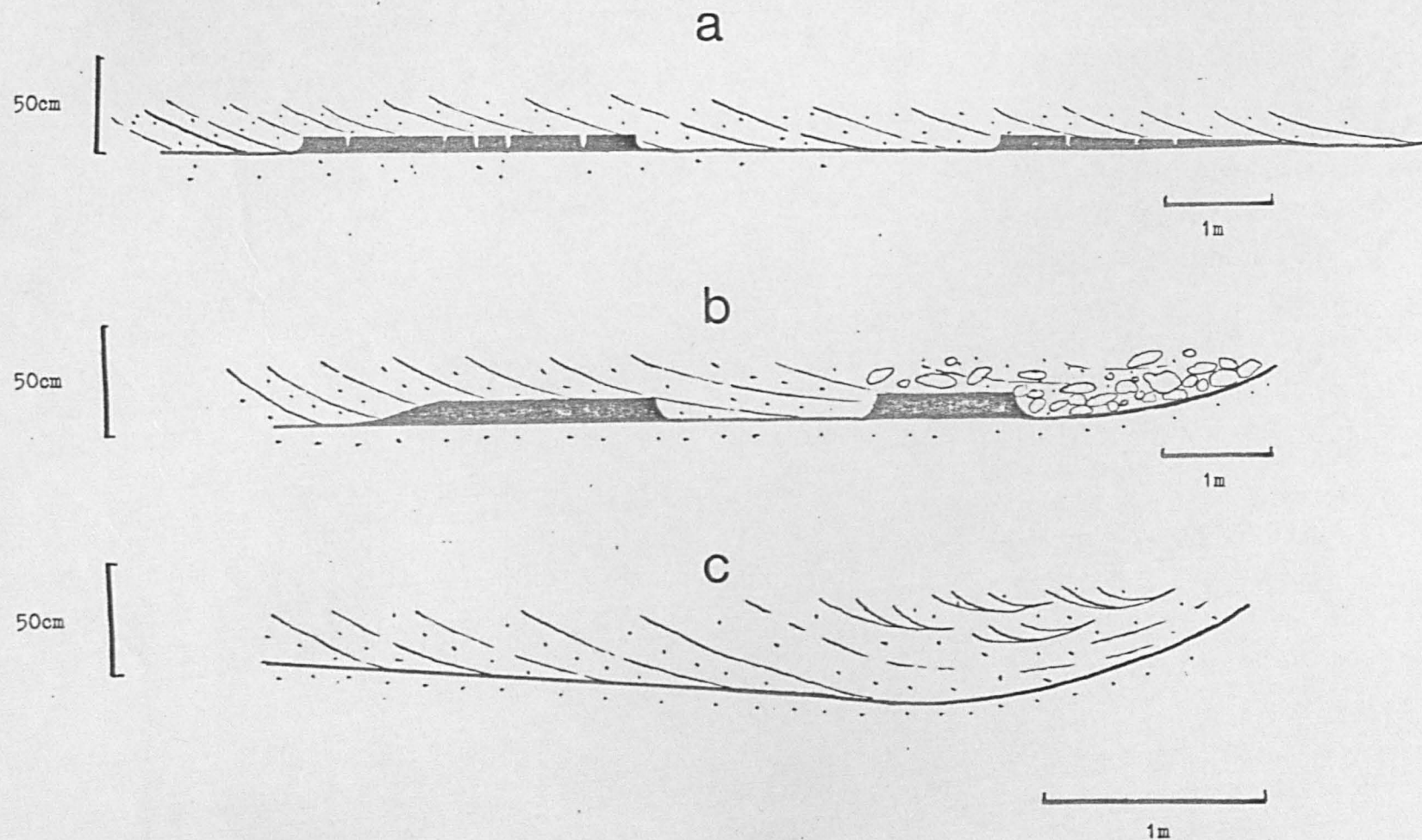


Figure 3.20 Field sketches from subfacies C4 showing the nature of cross-stratification, channel infilling, and the presence of siltstone (desiccated and partly eroded).

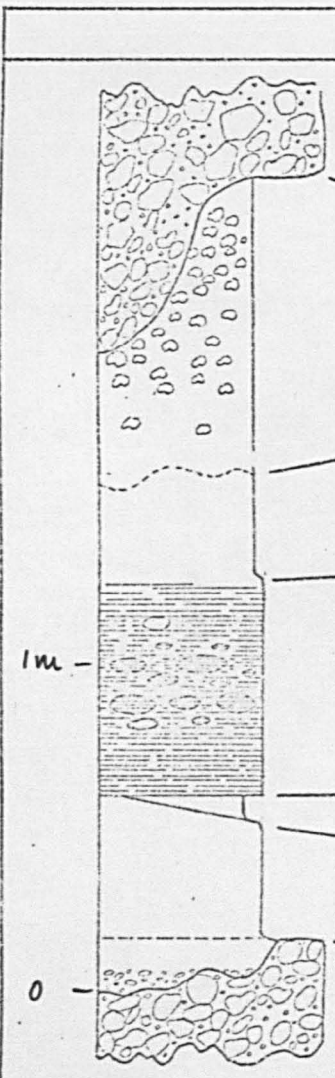
	MAIN FACTS.	INTERPRETATION.
	Coarse poorly sorted reddish brown slate rich conglomerate with calcareous fragments. Distinct erosive junction.	Re-advance of erosive Alluvial Fan processes into the marginal lacustrine environment. Erosion of lacustrine sediments.
	Reddish brown silty mudstones with abundant closely packed red-brown calcareous nodules.	Progressive regression of lake margin resulting in the oxidation of the original shallow water sediments, and allowing the development of extensive calcareous nodules. Continued deposition of finest sediment from out of suspension in a shallow lake margin environment.
	Massive grey-green silty mudstones.	Regressing deep water lake is replaced by subaerial lake margin sediments.
	Grey mudstone with poor Organic-Carbonate-Clastic lamination. Extensive development of carbonate fish bearing nodules.	Establishment of a permanent stratified lacustrine environment. Periodic influx of clastic detritus from suspension, and periodic precipitation of calcium carbonate. Well established vertebrate fauna. Environment distant from shoreline and probably records the maximum lake area and water depth.
	Grey-green plant bearing mudstone.	Lake margin environment with localised plant growth in shallow water.
	Massive grey mudstone, no apparent internal structure.	Establishment of shallow marginal lacustrine environment, with finest sediment being deposited from out of suspension.
	Undulating surface locally infilled by greenish silty gravel and red siltstone.	Lacustrine advance with localised reworking of initial Alluvial Fan sediments. Lake margin sediments reddened in an aerial oxidising environment.
	Coarse poorly-sorted reddish brown slate rich conglomerate.	Regressing Alluvial Fan sediments.

Figure 3.21 Lithoprobe through the Findon Fish Bed, showing logged section, and sedimentological interpretation from the present study.

Figure 3.22 Distribution of Middle Old Red Sandstone fish bearing horizons considered to be 'Achanarras' Limestone equivalents.

1. Gamrie (Den of Findon)
2. Tynet Burn.
3. Speyside.
4. Clava.
5. Black Isle (Millbui, Killin Burn).
6. Edderton Burn.
7. Niandt.
8. Achanarras.
9. Sandwick.(Orkney).
10. Melby. (Shetland).

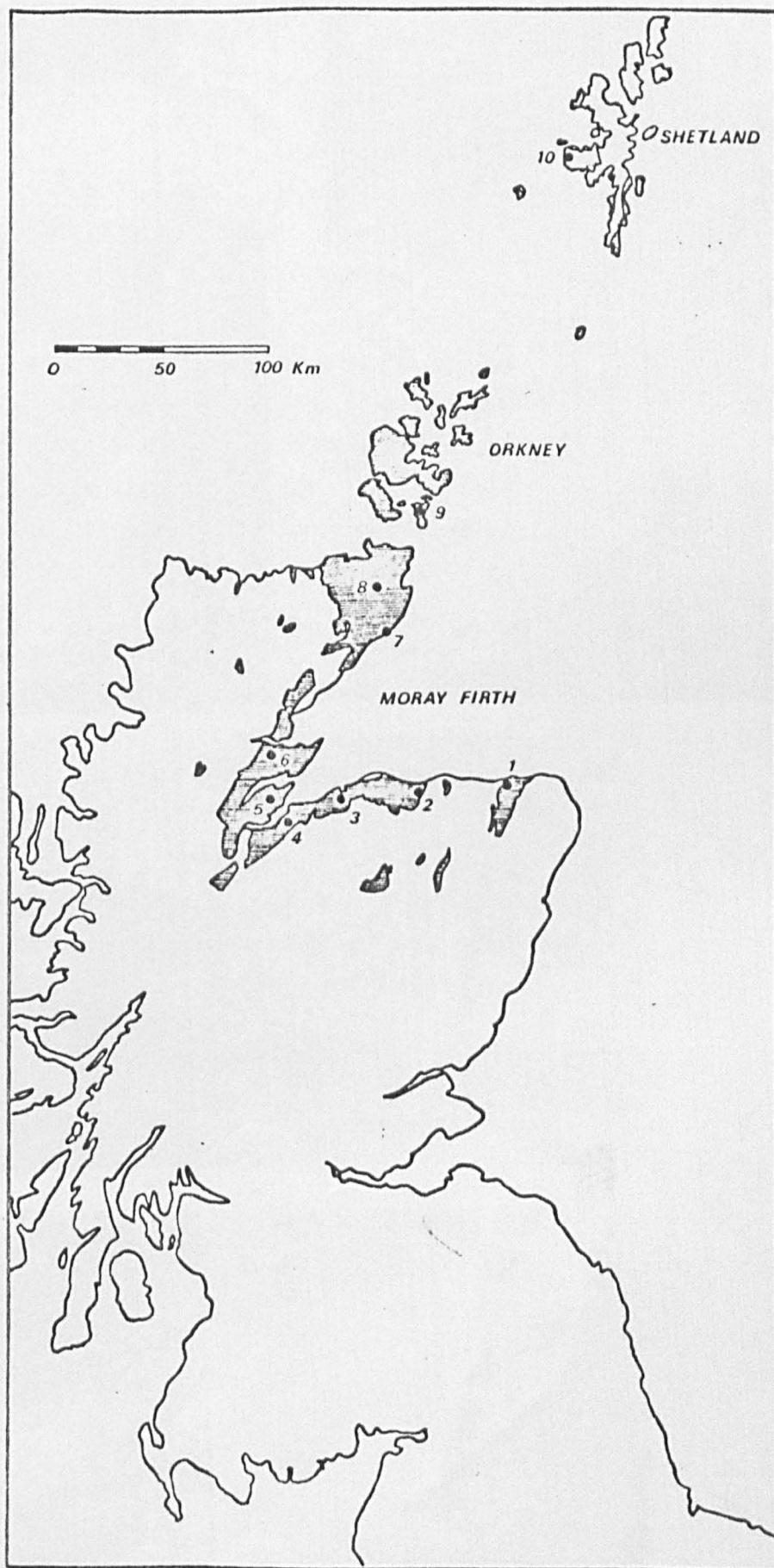


Plate 3.1 Sediments of subfacies Bla, (The Dundarg Castle Conglomerate Formation).

- A. Single sheet conglomerate (b), resting with slight erosion only upon massive sandstone (a). Note that the conglomerate unit shows a slight upward coarsening , and is overlain without erosion by multiple conglomerate sheets consisting mainly of feldspar rich gravels.

- B. General form of large channel conglomerates, showing coarse poorly sorted erosively based conglomerates with evidence of lateral migration. (scale : 10m exposed)

- C, D. Erosion at the base of single conglomerate sheets. Note that in both cases, erosion is restricted to minor scouring with coarse 'lag' infills.

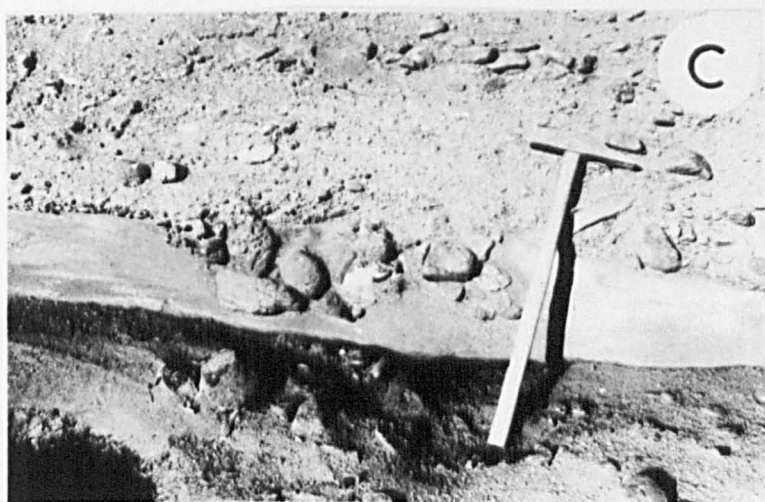
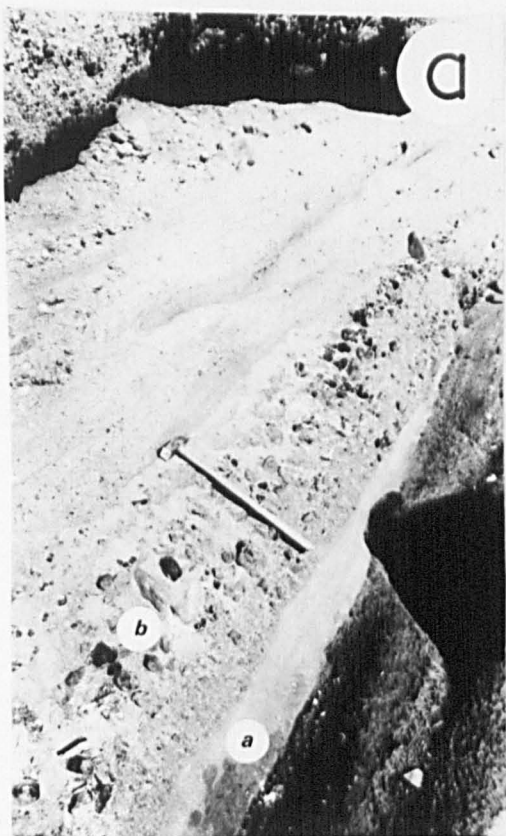
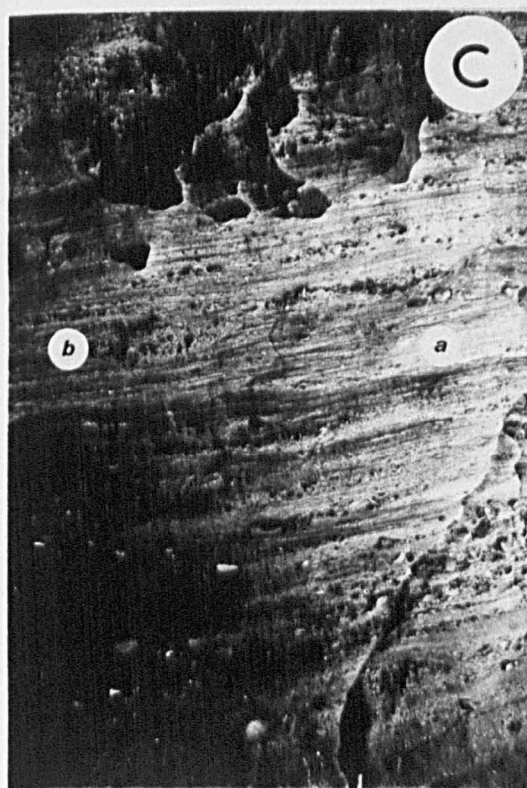
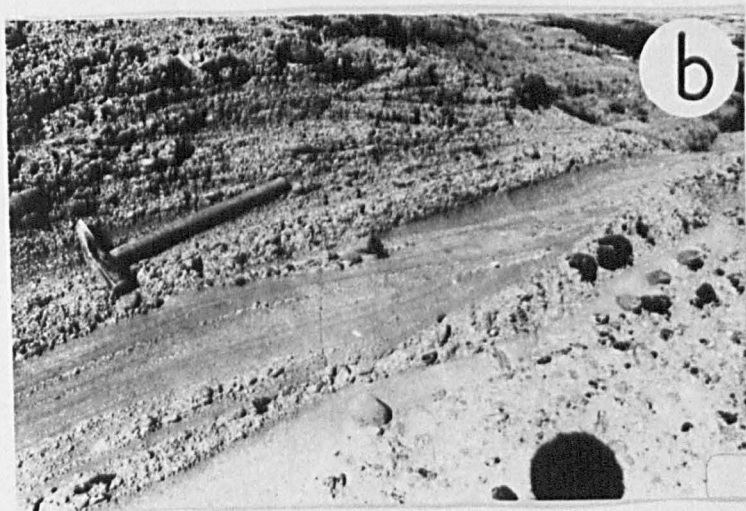
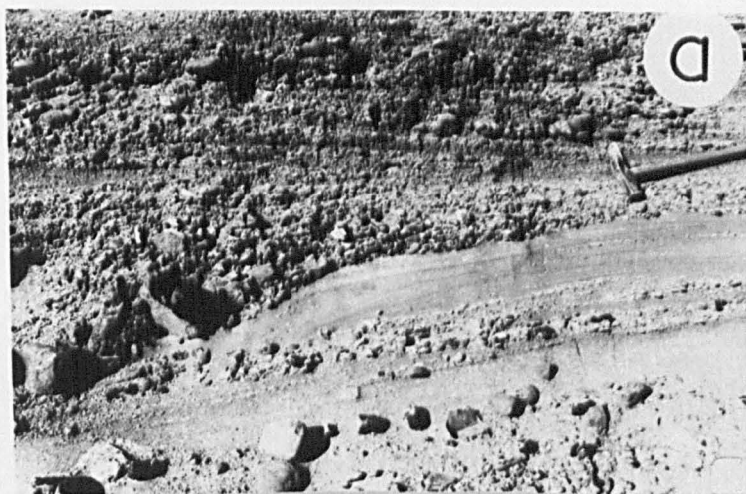


Plate 3.2 Sediments of subfacies Bla (the Dundarg Castle Conglomerate Formation).

- A. Minor erosion and channeling within multiple sheet conglomerates. Note that overall, the deposits are poorly sorted, and have an abundant feldspar gravel matrix.

- B. Multiple conglomerate sheets, showing the predominance of gravel and small pebbles within such conglomerates, and illustrating the magnitude of small erosion and development of minor cross-stratification.

- C. Multiple fine conglomerate sheets, showing again the predominance of gravels in such deposits, and the presence of minor erosion surfaces and scours which are possibly of aeolian origin, ie. deflation surfaces. (scale: exposed thickness 4m)



- A. Major channel infill structure showing the presence of (b) coarse conglomerate at the base of the channel, (a) whole channel deposit is overlain by multistorey conglomerate unit.

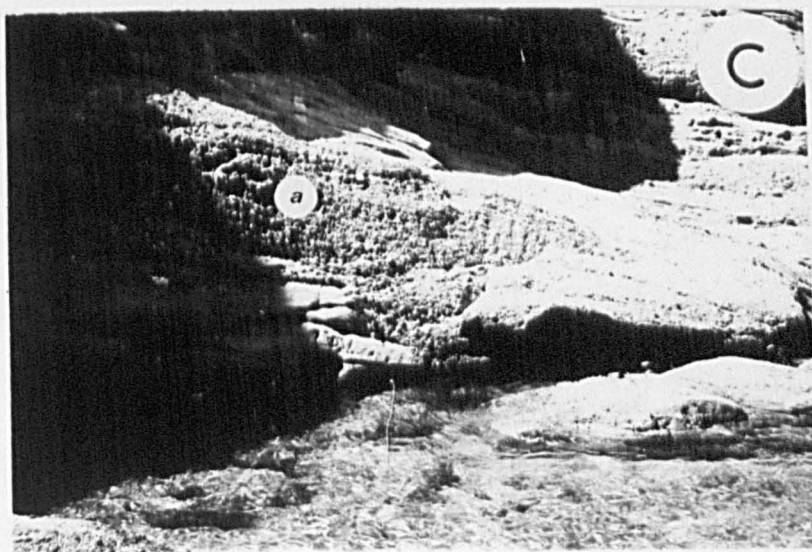
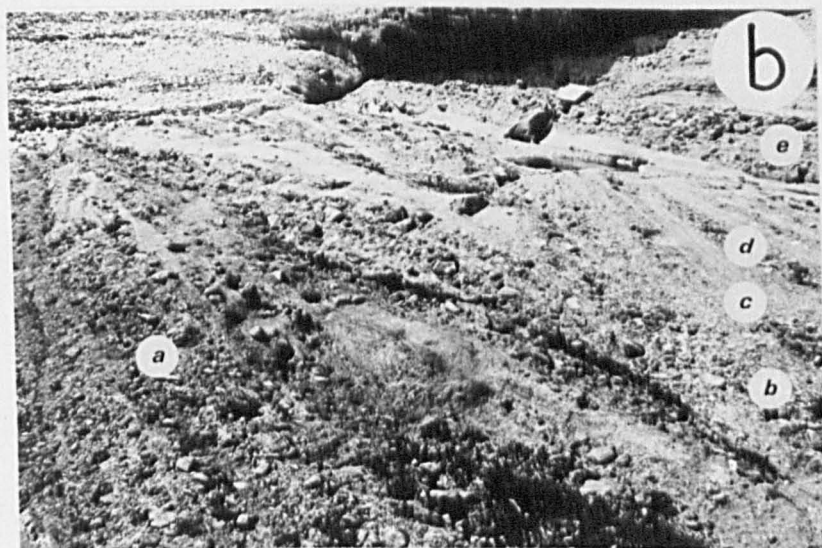
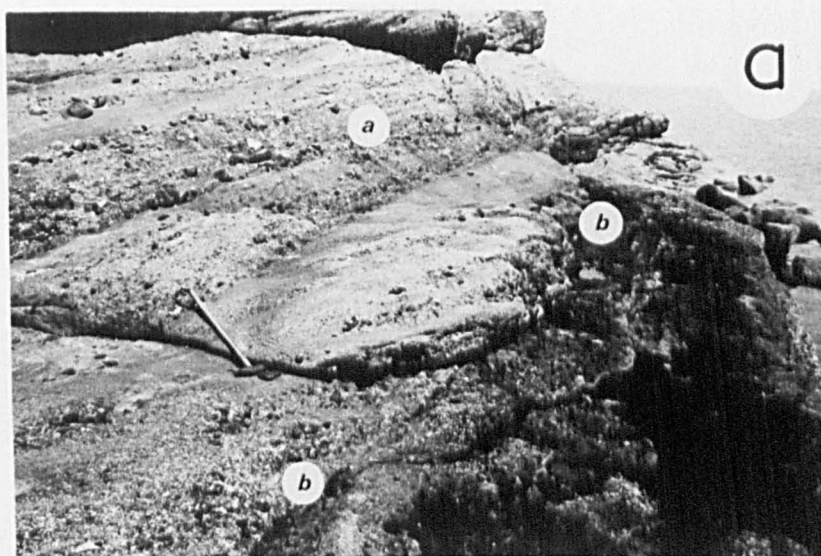
Note that the coarse channel fill conglomerate rises slightly up onto successive channel margins producing low angle cross-stratification. This feature is limited evidence of the lateral migration of channel units, significantly, lateral migration is never extensive and final infill usually 'chokes' the channel.

- B. The same channel unit as above showing that the channel is cut on multistorey conglomerate sheets (a) of a quite coarse nature.

The detailed form of the low angle (epsilon type) cross-stratification is shown to the right of the plate. Thin conglomerate sheets (b, c, and d) alternate with coarse sandstones forming thin conglomerate based fining units, each quite sharply based, and possibly implying pulsatory flow.

The overlying multiple conglomerate sheets are indicated at (e).

- C. A large channel infill, showing a coarse, massive, poorly sorted but multi storey infill. Note that the multiphase event is evident from thin sandy horizons within the conglomerate, conforming with 'stepping of the erosion surface (reactivation surfaces).
(scale: 6m exposed)



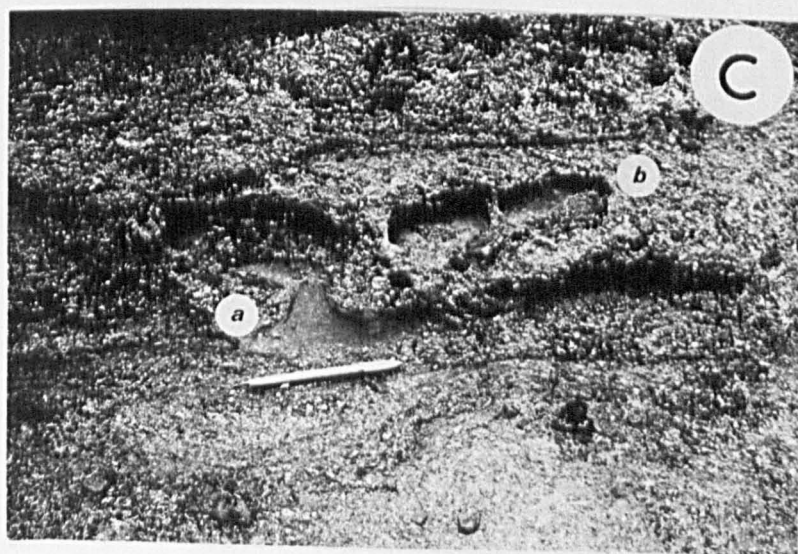
- A. Small erosion scour infilled by very well-sorted pebble conglomerate (a), occurring within multiple conglomerate sheet type deposits.
- B. General form of multiple conglomerate sheet type deposits.
- C. General form of channel fill conglomerate (small scale). Note poor sorting and wide size range. Although the coarse mode is poorly sorted, the fine population is very much diminished.
(scale: notebook at bottom right 14 cm wide)



A. Cross-stratified gravels

B. Cross-stratified sandy gravels

C. Intraformational 'sand clasts' (a and b).
Note the subsequent deformation (a).



A. General appearance of the lower member of the Castle Hill Sandstone sequence.

The illustration shows several typical features:

- (i) the presence of a rare but thick red clay level, (at the base of the section -lower left)
- (ii) convoluted sandstones (above hammer shaft),
- (iii) flat bedded sandstones above convolute horizon, note occasional pebble strings,
- (iv) followed by wedge shaped unit of cross-stratified sandstone with mudclasts on foresets,
- (v) followed by further convolute horizons.

Note abundant bleached or reduction zones.

B. Detailed view of cross-stratified unit figured in plate A showing abundant intraformational mudclasts upon foresets.

- (a) flat bedded sandstones with pebble strings,
- (b) cross-stratified horizon (note coin for scale)

C. At higher stratigraphic levels conglomerate becomes more abundant.

Flat bedded sandstone (a) with erosion scour infilled by cross-stratified gravel rich sandstone (b), and overlain by sandstone with abundant pebble and gravel strings (c).

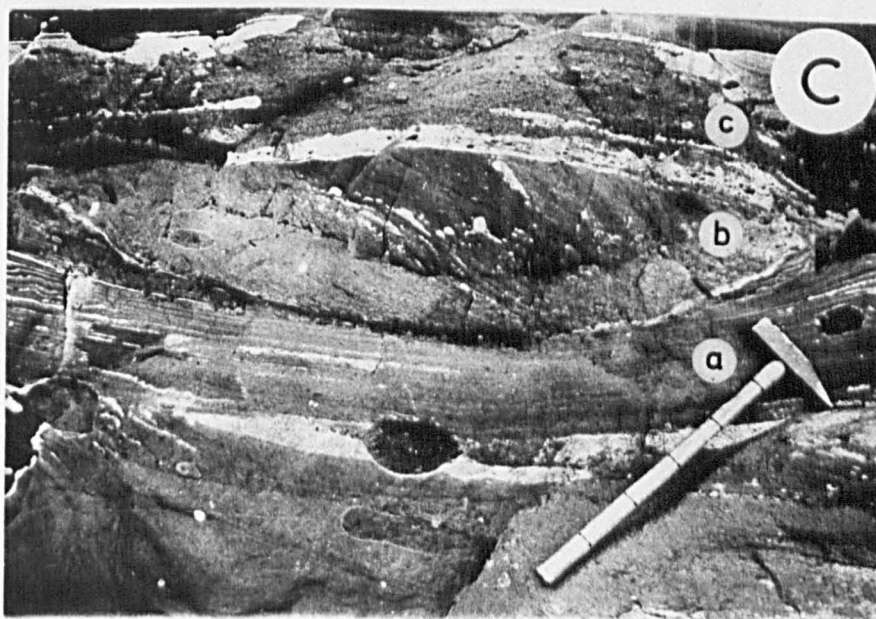
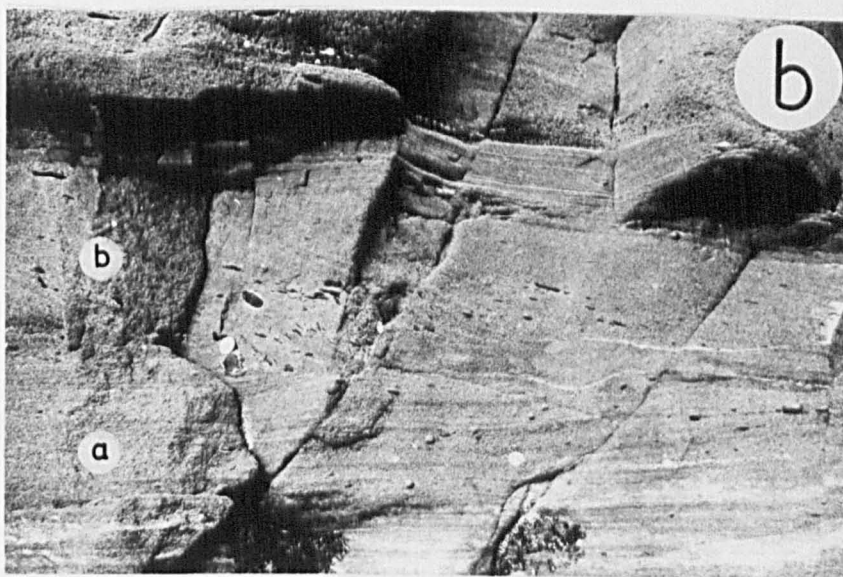


Plate 3.7 Sediments of subfacies B2a (The Castle Hill Sandstone Formation).

- A. Convolute bedded sandstones.

- B. Mudflake conglomerate within an extensively bleached zone. (scale 50 cm exposed)

- C. Small scour infilled with mudflake conglomerate.

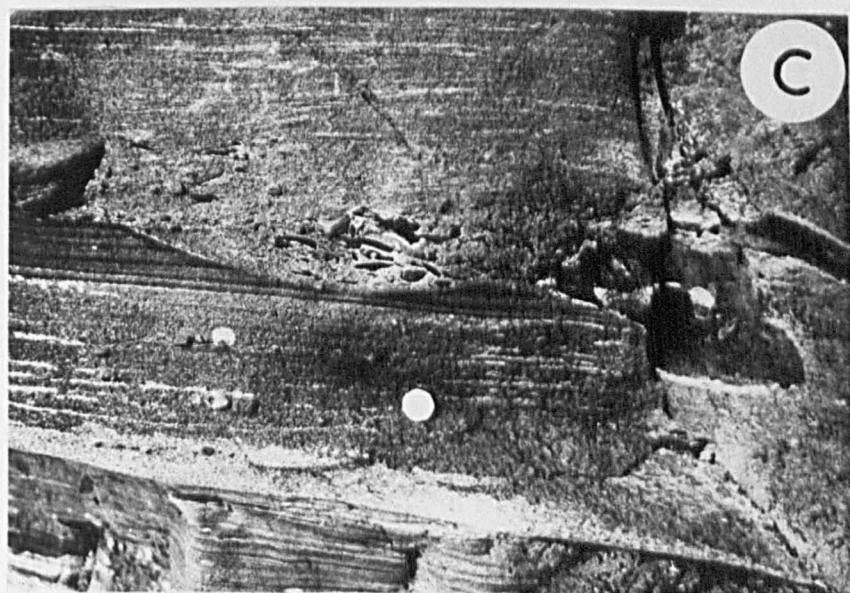
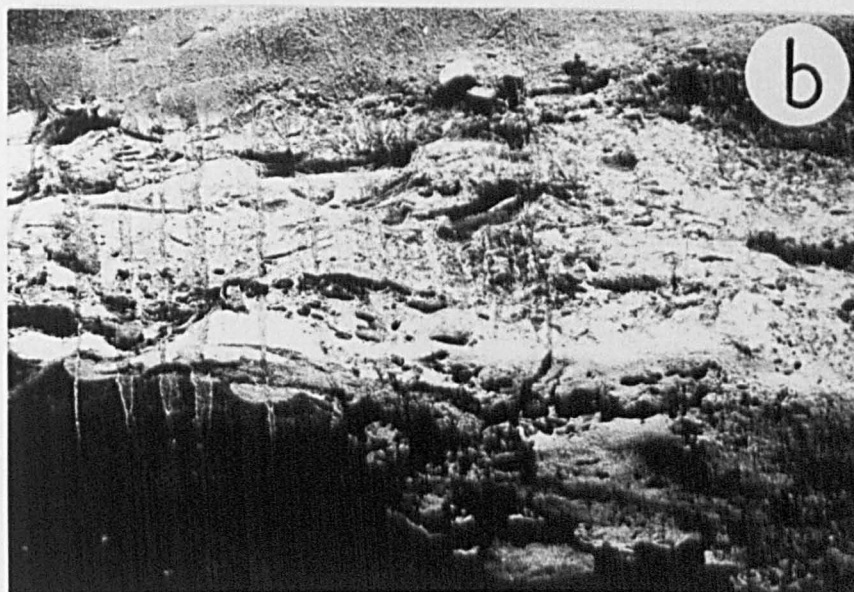
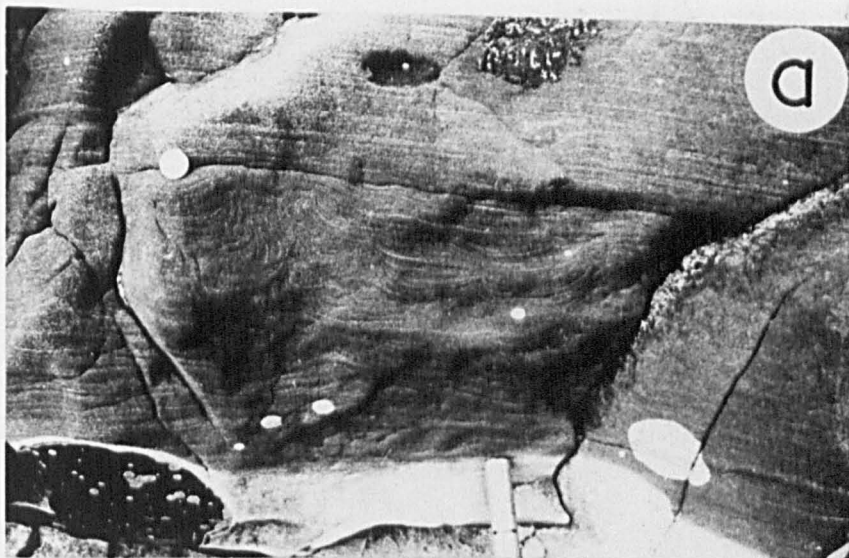


Plate 3.8 Sediments of subfacies B2a (The Castle Hill Sandstone Formation).

- A. General form of the upper member of the Castle Hill Sandstone Formation.
As in the Dundarg Castle Conglomerate sequence, subfacies Bla, multiple thin conglomerate sheets (a), alternate with coarse sandstones (b), and small erosively based conglomerate sheets (c).
(scale: thickness exposed 4m)
- B. Detail of conglomerate from upper member, showing quite fine, but poorly sorted gravel grade conglomerate.
- C. Unusual channel fill from within the upper member, showing an erosively based channel unit infilled by poorly sorted conglomerate (a) (note blade like fragments of slate rich conglomerate). Within the channel unit, a large intraformational block of sandstone (b) showing disoriented bedding occurs, and offers clear evidence of bank caving and floodplain destruction.

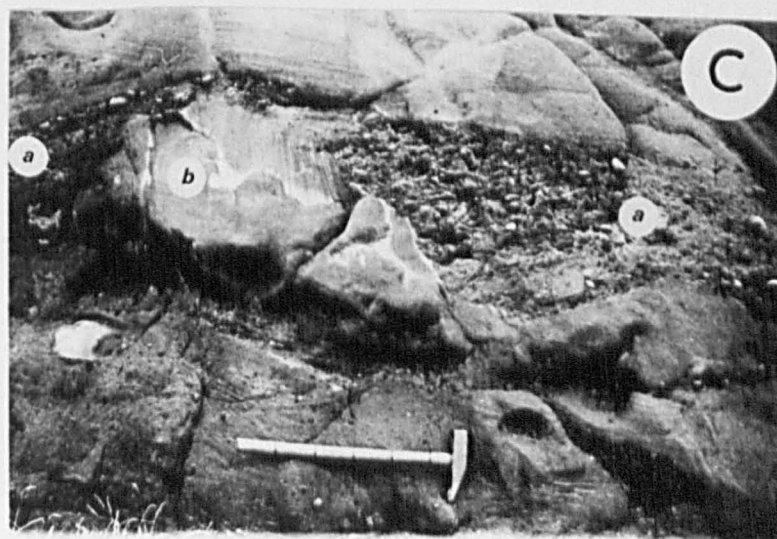
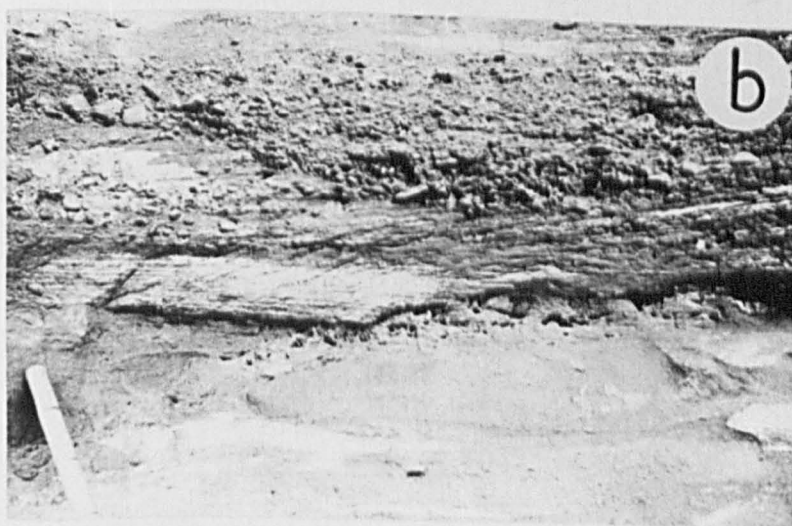
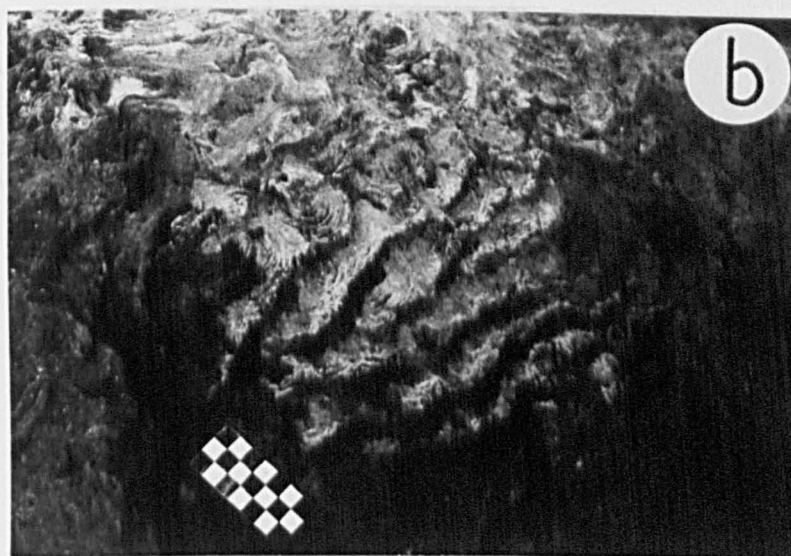
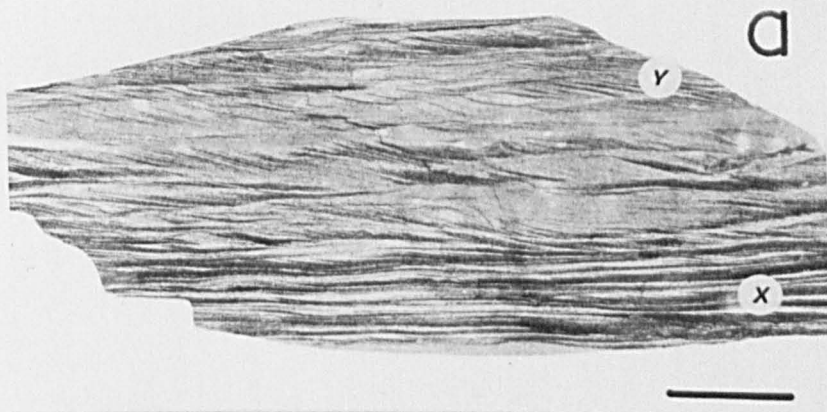


Plate 3.9 Sediments of subfacies C3 (The West Harbour Formation).

- A. Polished impregnated block of typical West Harbour Formation sandstone.
The sandstones are highly micaceous, very fine grained, and occur in units commonly based by flat bedding (x) from which ripple cross-lamination develops (y), commonly climbing ripple cross-lamination.
(scale bar = 5 cm)
- B, C. Bedding surfaces preserving trains of ripples (asymmetric) responsible for the production of the above illustrated ripple lamination.



- (a) siltstone of previous cycle sharply overlain by ripple-drifted sandstone (b), which develops rapidly into climbing ripple lamination (c). The unit fines
- A. Typical coarse portion to a cycle within the lower member.
Underlying cycle :
 (a) siltstone fining rapidly into very fine siltstone / mudstone (b),
 (c) interdigitation of rippled sandstone sheets,
 (d) final deposit of thinly laminated mudstone.
Overlying cycle :
 (e) slight erosion and deposition of sandstone as ripple-drifted sand sheets,
 (f) climbing ripple cross-lamination develops rapidly and forms most of coarse member,
 (g) ripples become washed out prior to the rapid fining of grain size into the overlying siltstone portion of the cycle.
- B. Further example of coarse portion to cycle :
 (a) underlying sandstone grading rapidly into siltstone (b),
 (c) overlying cycle starts with no apparent erosion and consists of ripple laminated sandstones throughout (d), note the increase in ripple size at the top of the unit (e), prior to the siltstone portion of the cycle (f).
- C. (a) ripple laminated sandstone overlain by silt portion of cycle (b).
Followed by next cycle (c) consisting initially of rippled sandstones (c), but cycle has been eroded and infilled by planar cross-stratified sandstone (d) or avalanche front cross-stratification.
- D. Further example of form of cycle:
 (a) laminated mudstone overlain by base of next cycle (b), consisting of ripple-laminated sandstone, overlain by flat bedded sandstones (c) before decreasing in grain size and grading into siltstone (d).

(continued)

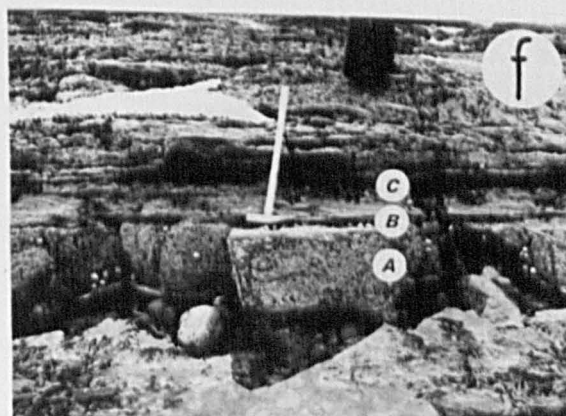
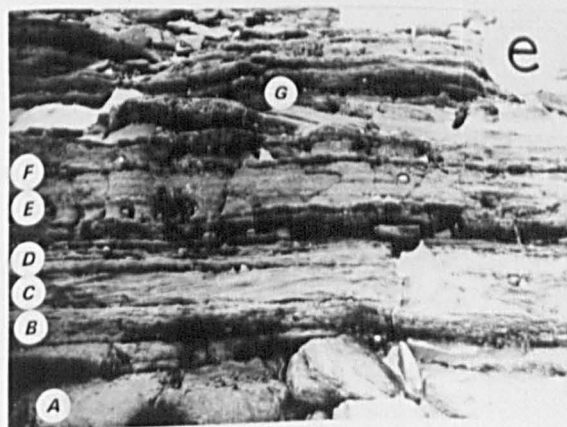
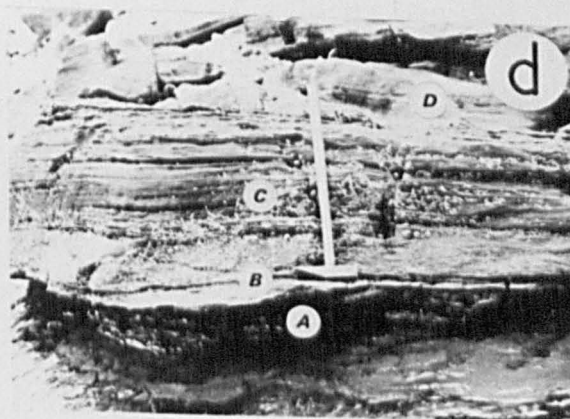
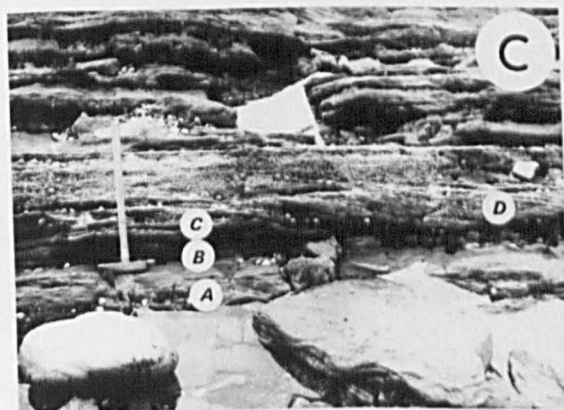
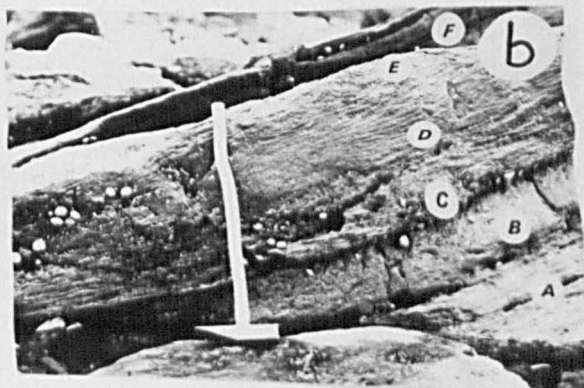
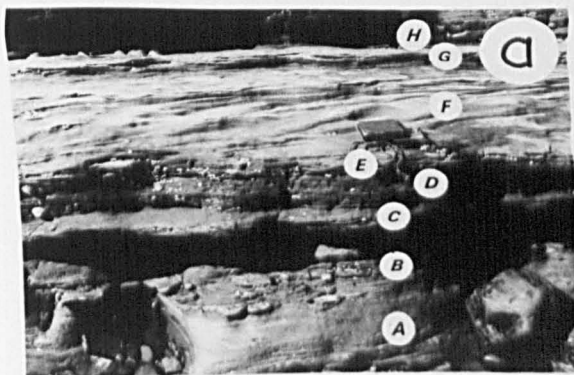


Plate 3.11 Sediments of subfacies C3 (The West Harbour Formation).

A series of plates illustrating the general form of the sediments of the upper West Harbour member.

- A. Broad cross stratified channel infills forming a multistorey unit.

- B. Detail of channel infill.
 - (a) underlying siltstone followed by erosive channel sandstone (b) with abundant ripple laminated sandstone infill. Unit (b) grades into coarse siltstone with parallel bedding, before being partially eroded and overlain by the following channel unit (c), again largely ripple laminated sandstone. Unit (c) finally grades into siltstone and eventually mudstone before being capped by a broad sheet of ripple laminated sandstone (d).

- C. Further example of channel infills showing identical series of events as in previous plate. Note that final capping of sandstone is laterally persistent, comparable to cycles within the lower member.

- D. Detail of channel fill sandstone.
 - (a) underlying siltstone,
 - (b) ripple drift infilling of channel unit, fining into siltstone,
 - (c) mudflake conglomerate of base of succeeding erosion surface,
 - (d) succeeding channel infill.

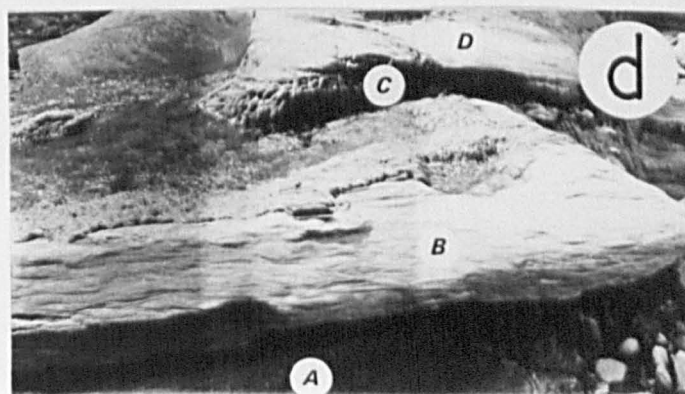
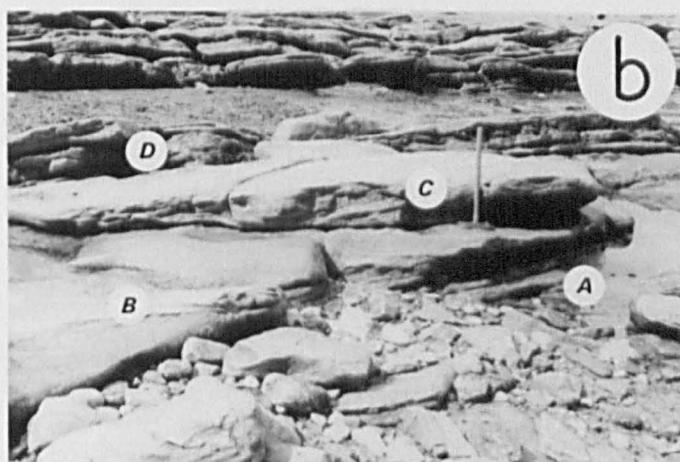
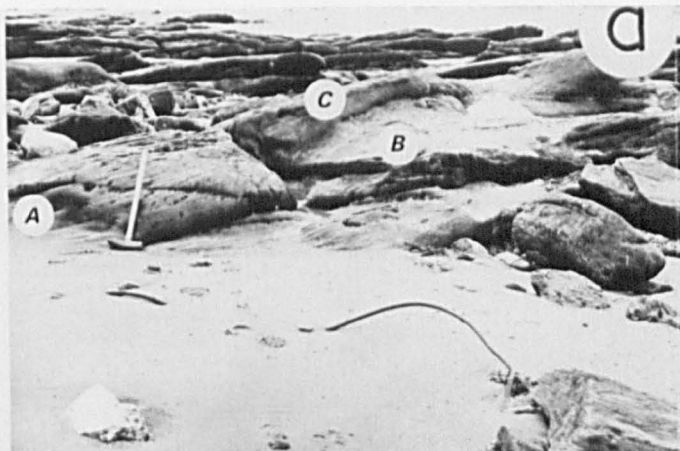


Plate 3.12 Sediments of subfacies C4 (Dundarg Castle Sandstone Formation).

Detail of broad gravel filled channel unit showing the relatively shallow depression (smooth based) infilled by massive gravel. Note that the gravel floats within a coarse sand matrix (a).

Detail of the form of a portion of one of the subfacies C4 coarse members.

Note the occurrence of distinct sharp based units of gravel rich sandstone resting upon conglomerate (a). The unit of gravely sandstone (b) coarsens upwards into a fine pebble / gravel conglomerate.

Coarsening upward units in similar deposits are often ascribed to the migration of longitudinal bars.

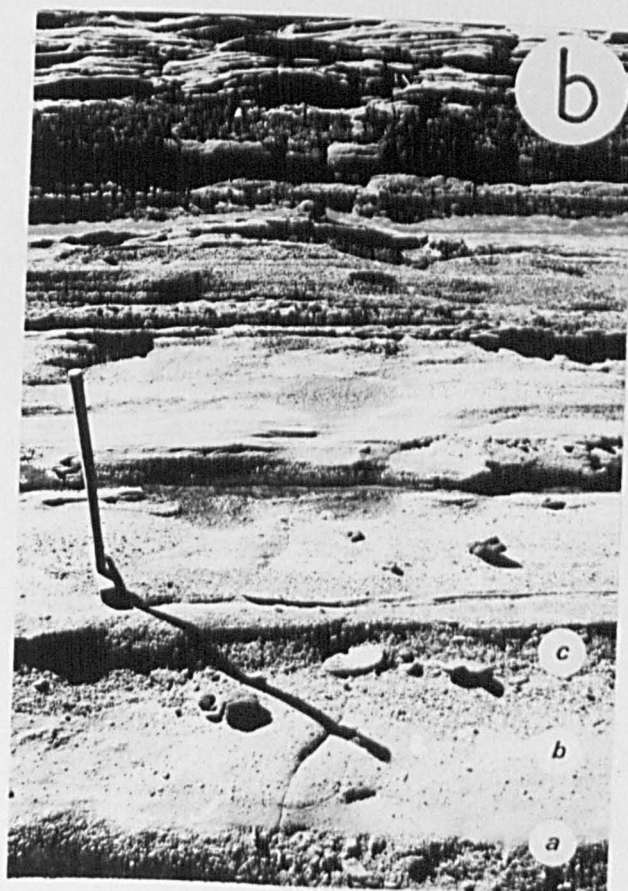
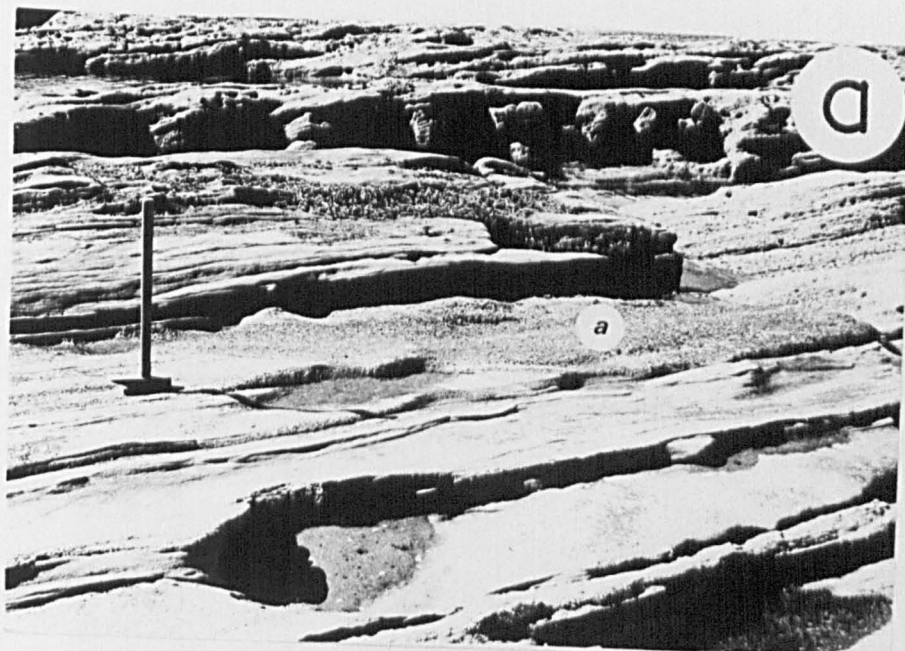
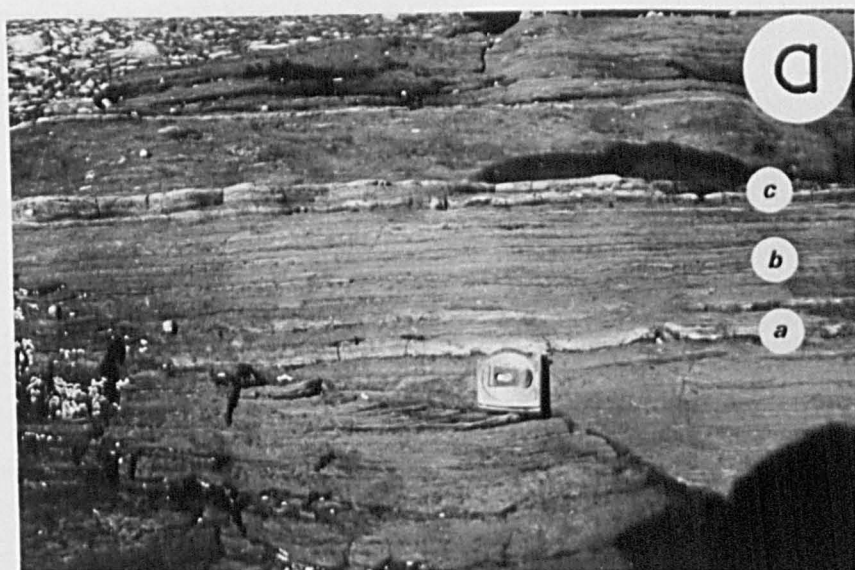


Plate 3.13 Sediments of subfacies C4 (The Dundarg Castle Sandstone Formation).

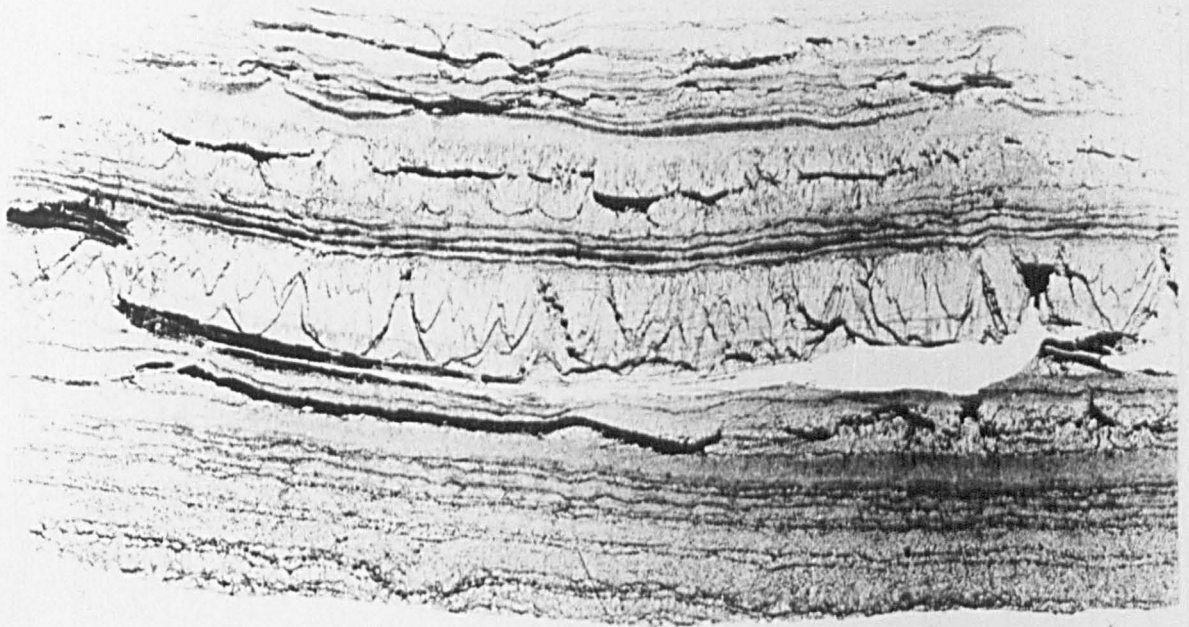
- A. Typical appearance of deposits from within the fine members of the Dundarg Castle Sandstone Formation.
(a) fine grained sandstones (always very thin) alternate with thinly interbedded fine and very fine wavy-bedded type of sandstones (b).

- B. Preservation of symmetrical ripples within wavy-bedded very fine sandstones. Ripple form has a thin mud veneer, and ripple tops have been eroded by subsequent deposits.

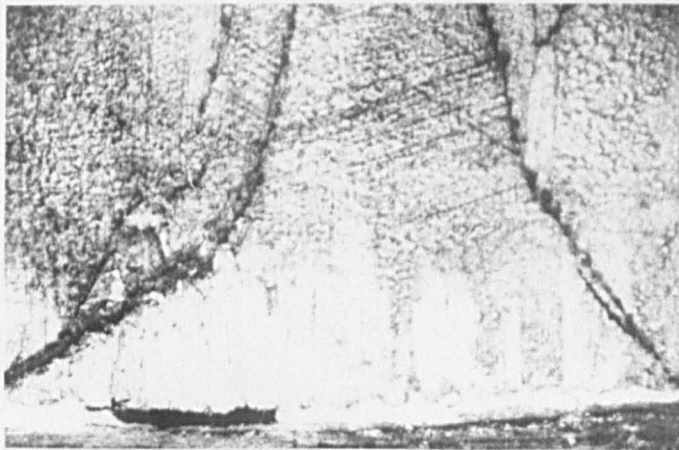
- C. Wavy-bedded deposits showing convolute bedding.



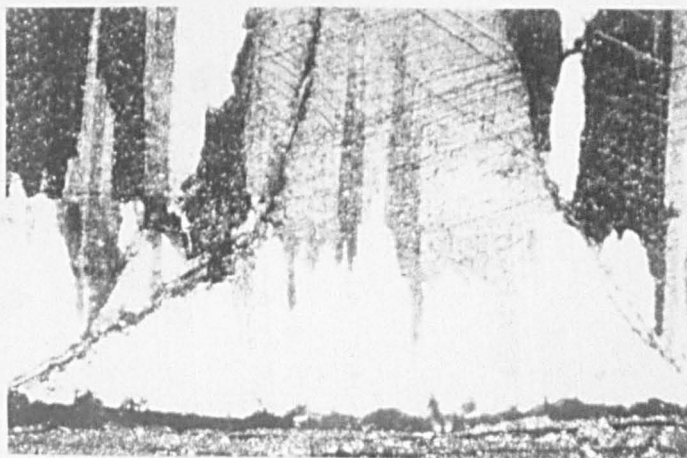
- A Photograph of an acetate peel from a nodule from the Findon Fish Bed.
Note the presence of fine organic / carbonate / clastic lamination (very much expanded by carbonate within nodules), and also the well-developed 'cone in cone' structure.
The cone in cone development shows several important features including the major expansion of individual layers (see the stepped portion of a cone in the centre of the field), and also the two dominant angles of cone development.
The magnitude of the cone angle is generally accepted to indicate overburden pressure, and therefore a sharp angle of cone may correspond to early nodule development, whilst a low angle records subsequent growth under higher pressures.
(scale: width of field 6 cm)
- B, C. Details of the two angles of cone development, showing two stages of calcite crystallisation (plate b plane polarised light; Plate c, crossed polars)
(scale: width of field 1cm)



a



b



c

CHAPTER 4

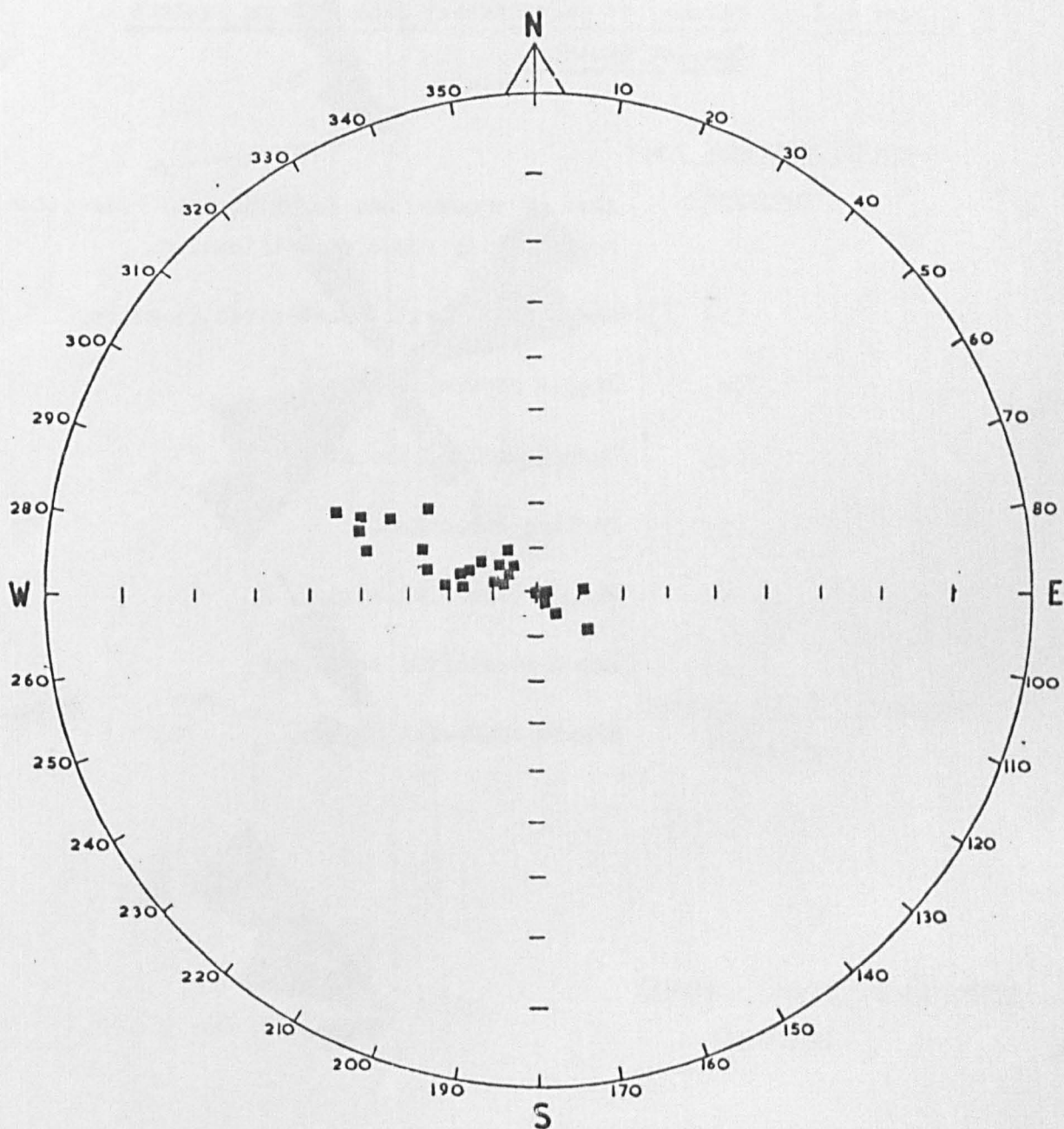


Figure 4.1 Stereographic projection of the orientation and inclination
of large blade and disc shaped blocks within the Fleckies
Meadow Conglomerate. (Data corrected for dip of strata.)

Figure 4.2

Summary of paleocurrent data for the Eastern Coastal Section.

- (a) Axes of troughs and large scours, direction confirmed by cross stratification.
- (b) Channel axes with cross-stratification.
- (c) Ripple cross-lamination.
- (d) Symmetrical ripple axes.
- (e) Parting lineation.
- (f) Ripple cross-lamination.
- (g) Cross-stratified sandstone.
- (h) Ripple cross-lamination.

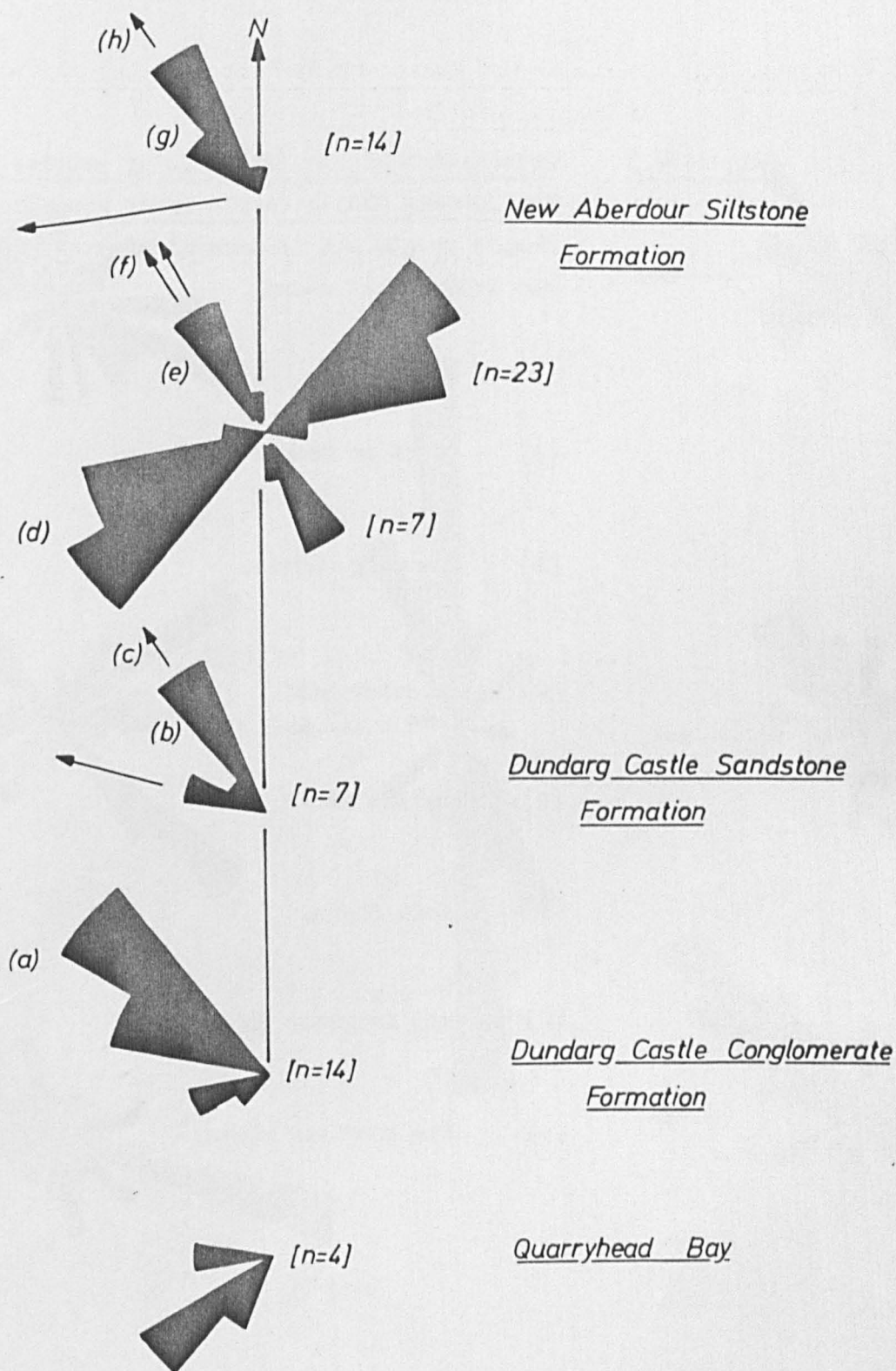


Figure 4.3

Orientation of the long axes of pebbles within
the Dundarg Castle Conglomerate Formation.

Sample points are in ascending stratigraphic order,
and N=50 in all cases.

- (A) Port an Doon.
- (B) Dundarg Castle.
- (C) Counter Head.
- (D) Little Haven.
- (E) Boat Shore.
- (F) New Aberdour Shore.
- (G) New Aberdour Shore.

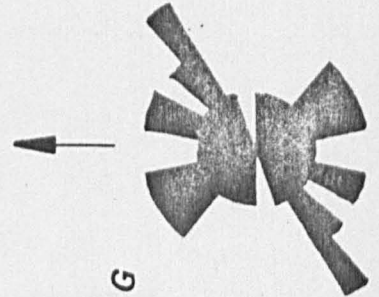
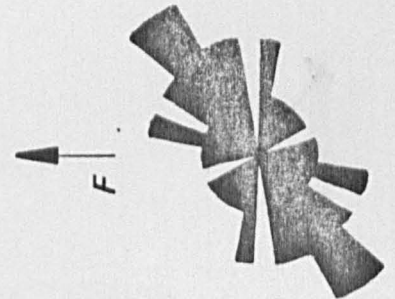
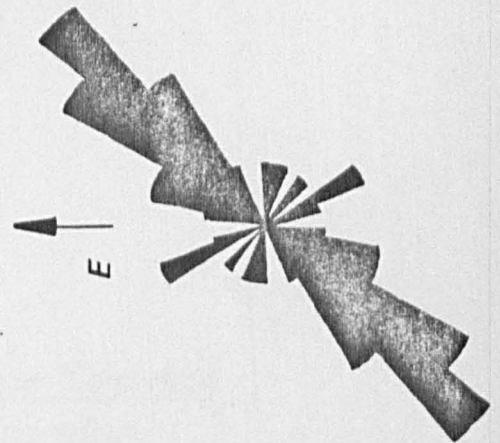
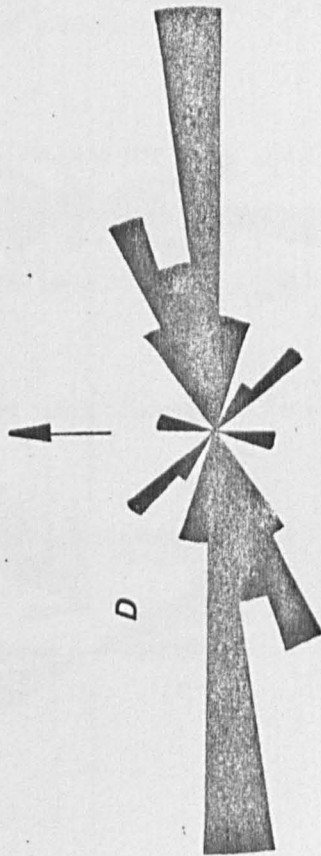
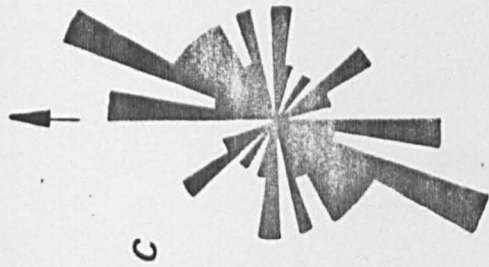
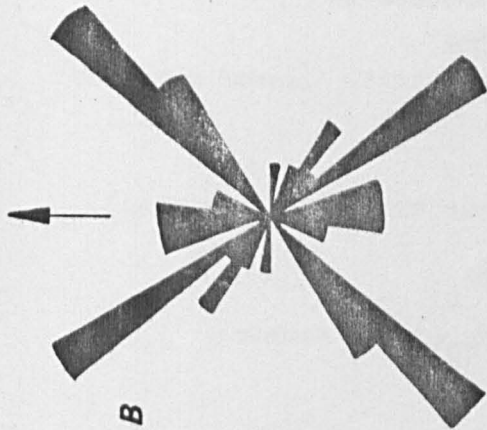
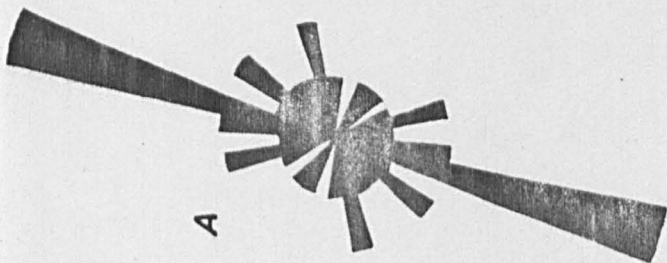


Figure 4.4

Summary of paleocurrent data for the lower part
of the Western Coastal Section sequence.

- (a) Cross-stratification.
- (b) Symmetrical ripple axes.
- (c) Cross-lamination.
- (d) Symmetrical ripple axes. (lower member).
- (e) Symmetrical ripple axes. (upper member).
- (f) Cross-lamination. (upper member).

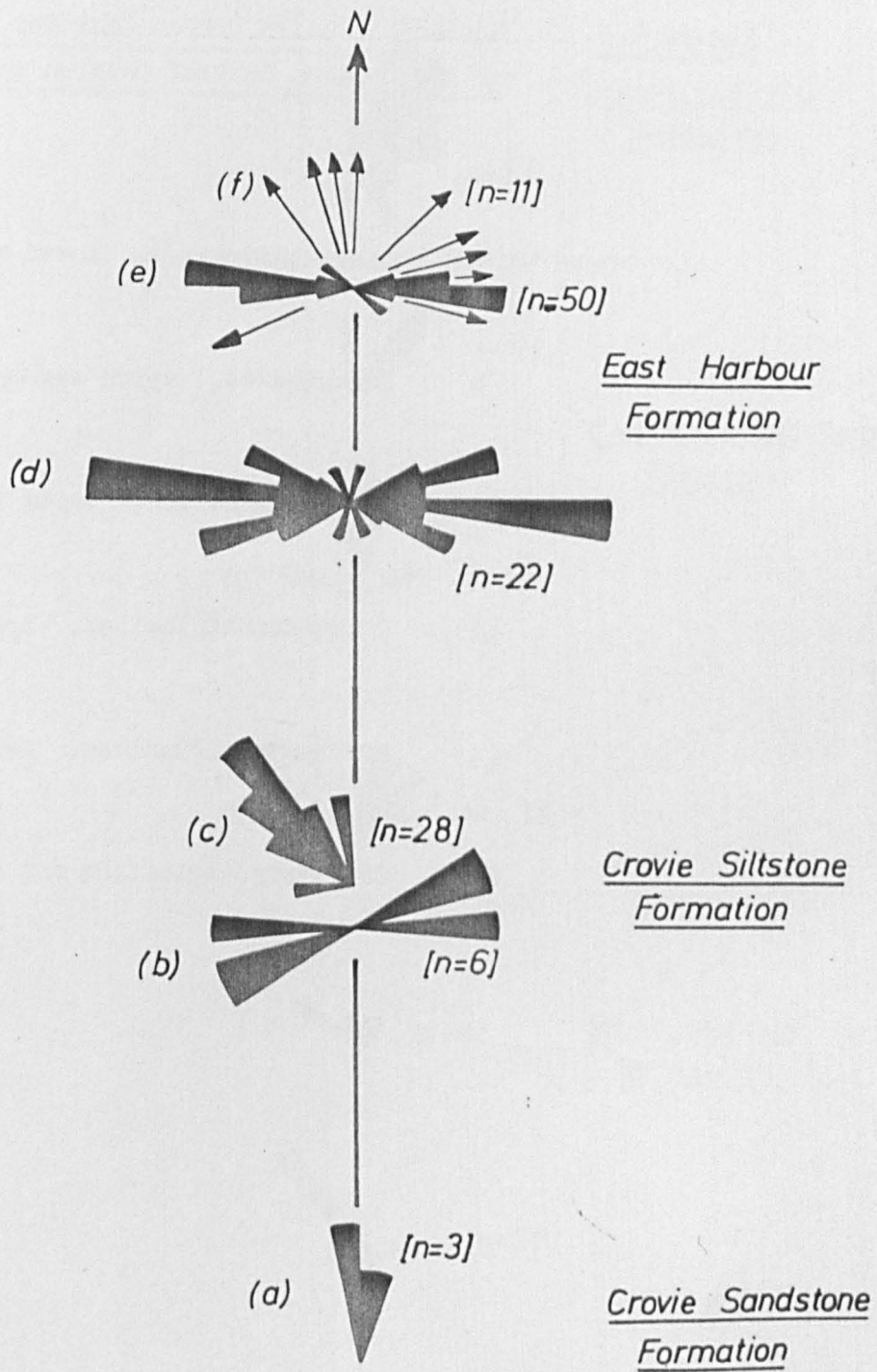


Figure 4.5

Summary of paleocurrent data for the upper part
of the Western Coastal Section sequence.

- (a) Cross-lamination, lower member.
- (b) Trough axes, upper member.
- (c) Cross-lamination, upper member.
- (d) Cross-stratification, lower fine member.
- (e) Cross-stratification, upper coarse member.
- (f) Cross-stratification and imbrication.

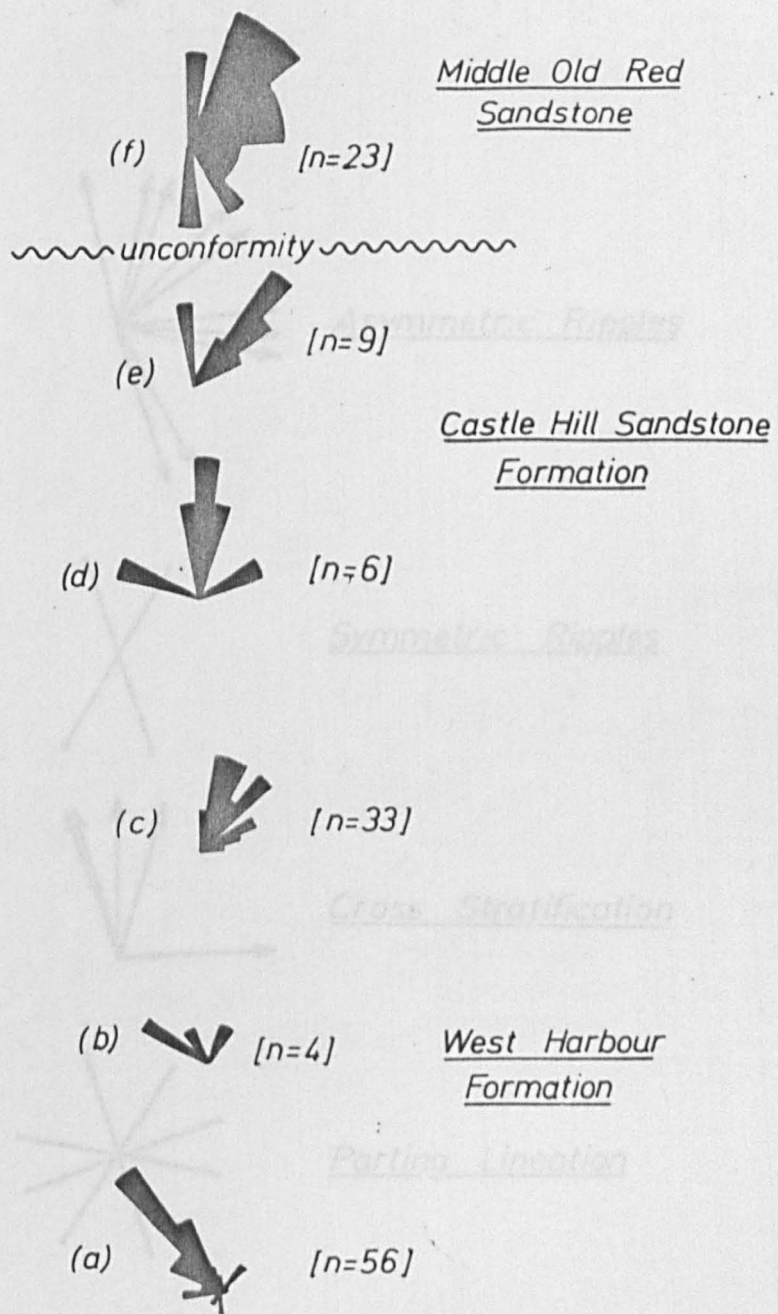
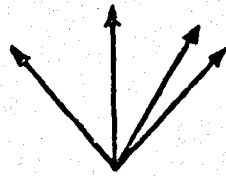
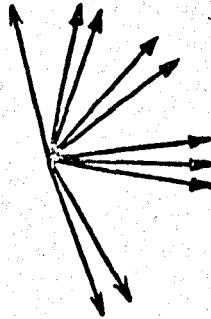


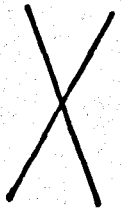
Figure 4.6 Summary of mud crack data.



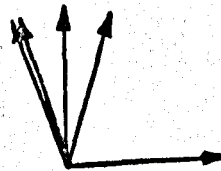
Channel Axes



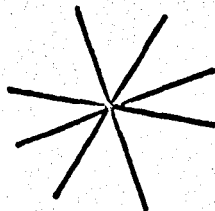
Asymmetric Ripples



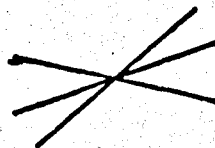
Symmetric Ripples



Cross Stratification



Parting Lineation



Drag Marks



Imbrication

Figure 4.6 Summary of Rhynie paleocurrent data.

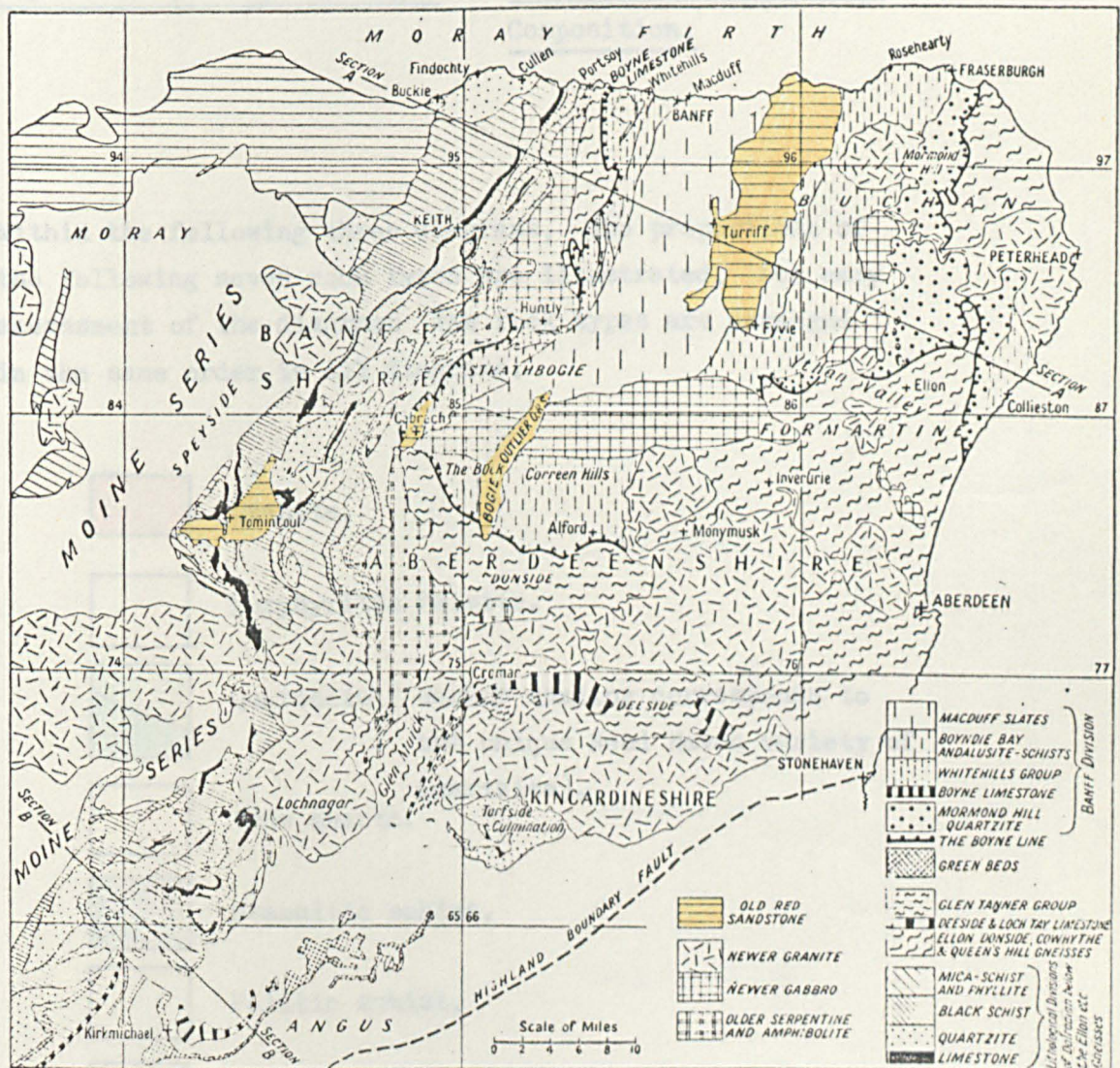
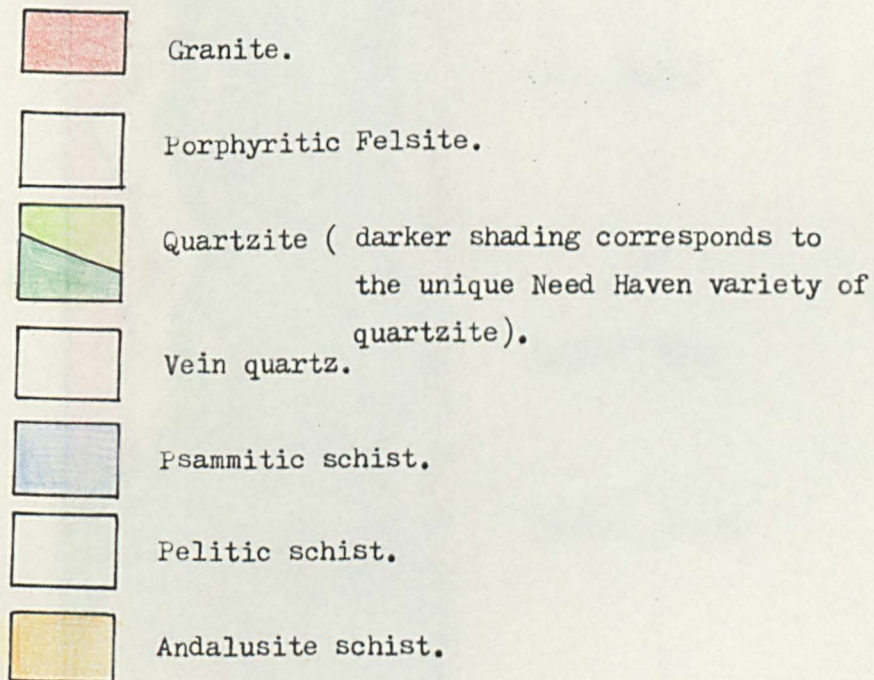


Figure 4.7 Generalised geological map of northeastern Scotland illustrating the composition of the source area for the sediments of the study area.

Figures 4.8, 4.9, and 4.10.

Analysis of Conglomerate
Composition.

Within the following three diagrams, the proportions of the following seven rock types are illustrated, for easy assessment of the diagrams the rock types are arranged in the same order in all diagrams.





New Aberdour Shore

Boat Shore

Little Haven

Counter Head

Dundarg Castle

Fleckies Meadow

Port an Doon

Figure 4.8 Summary of conglomerate composition for the Eastern Coastal Section.

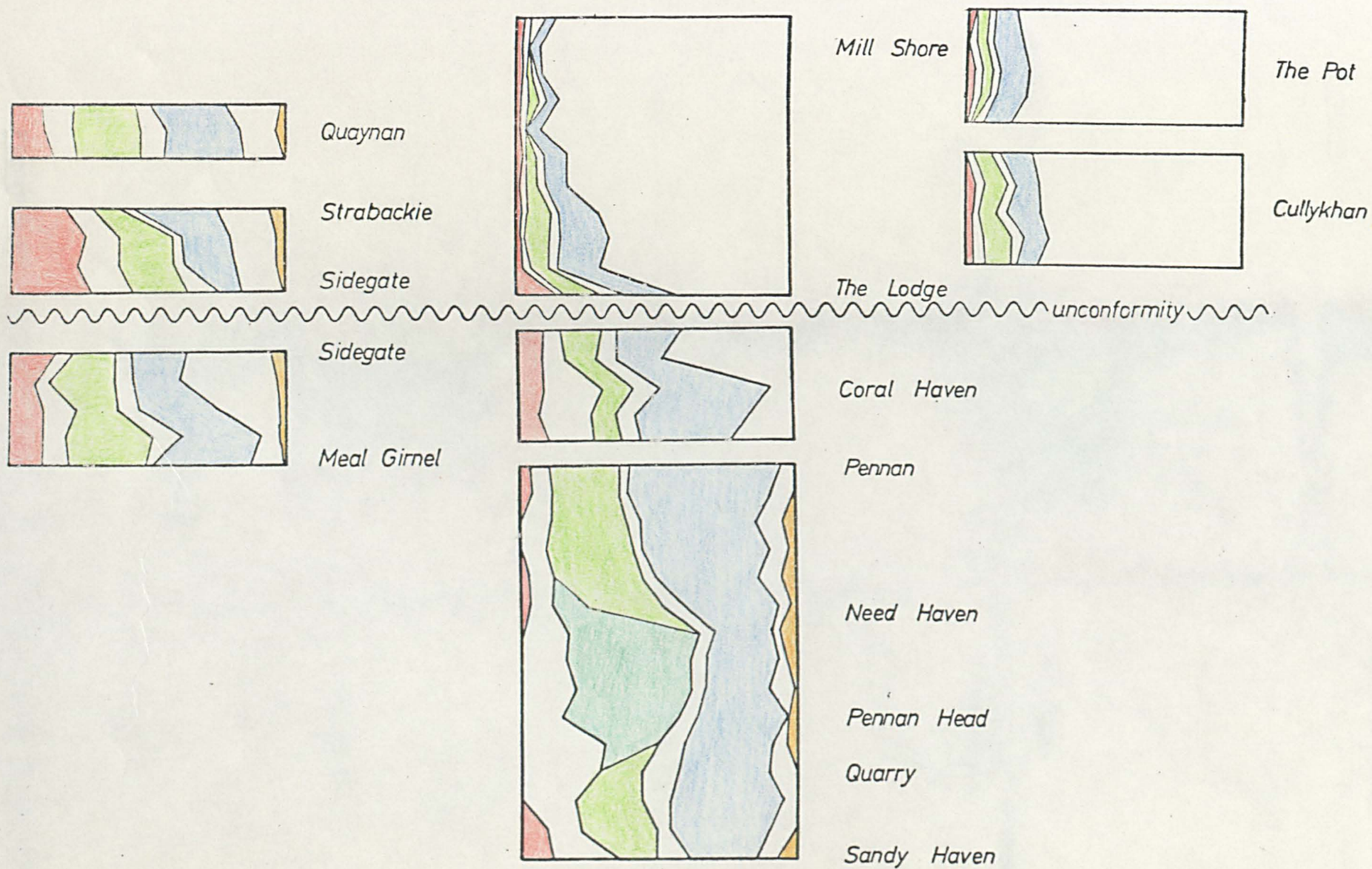


Figure 4.9 Summary of conglomerate composition for the Central Coastal Section.

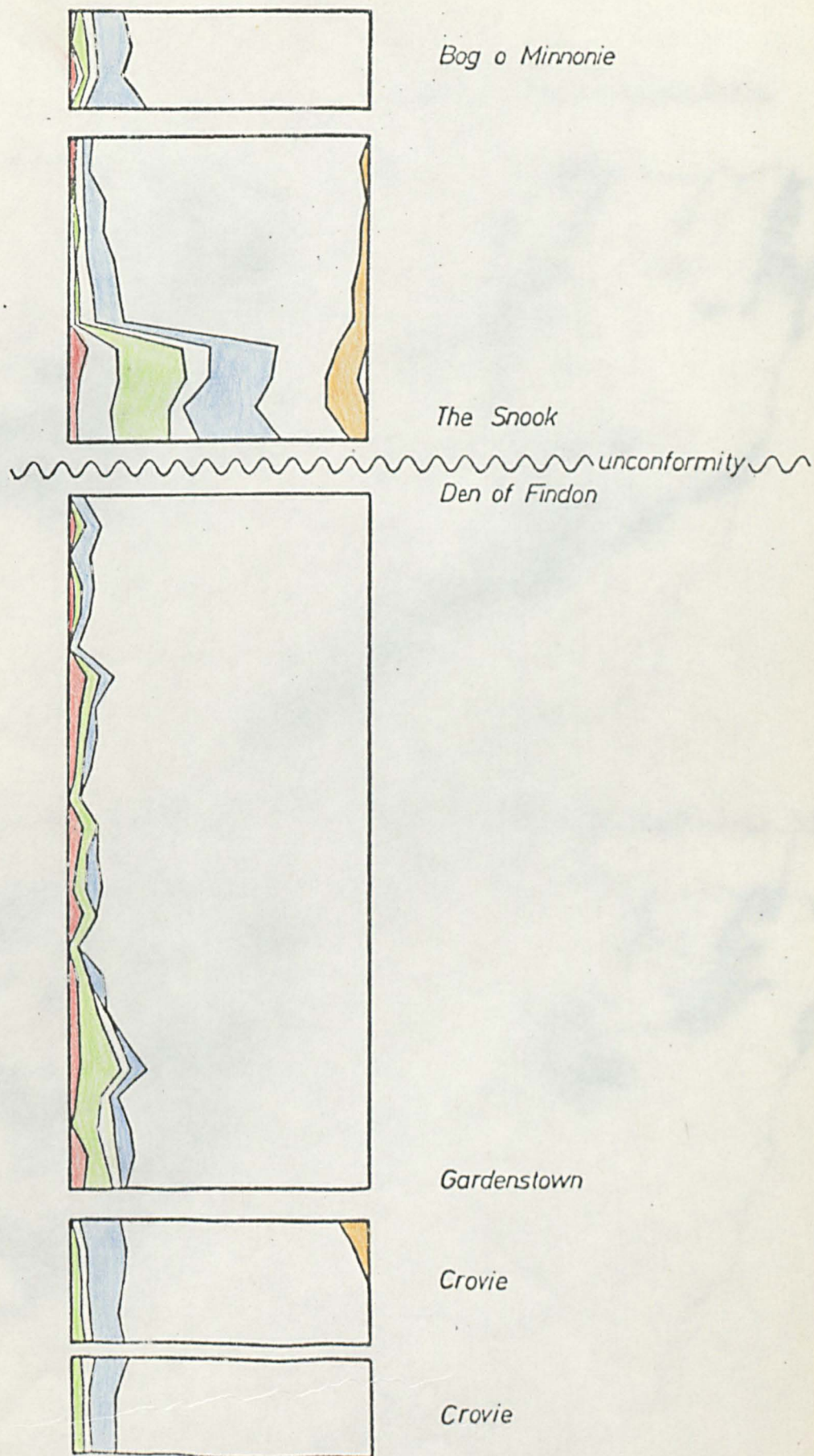
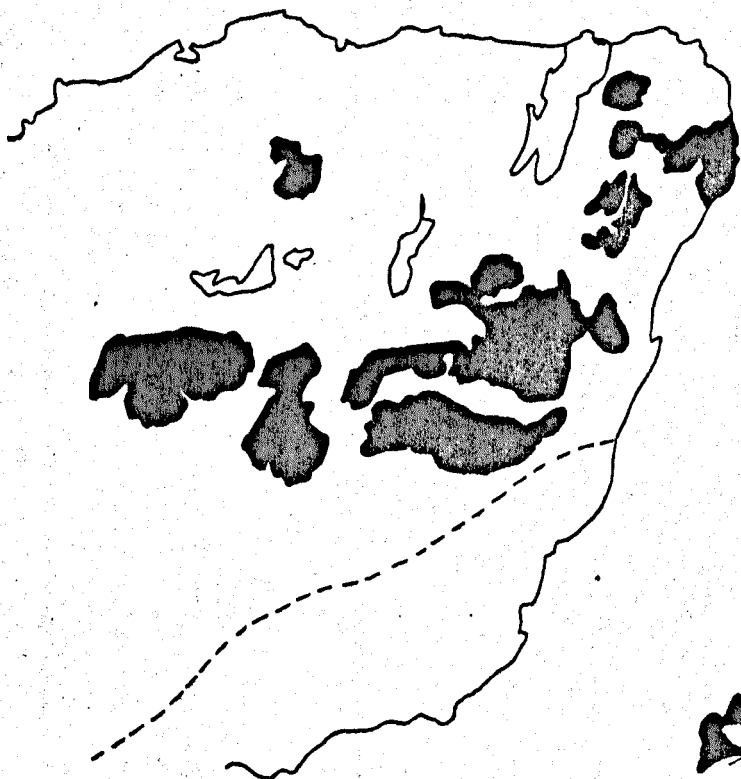
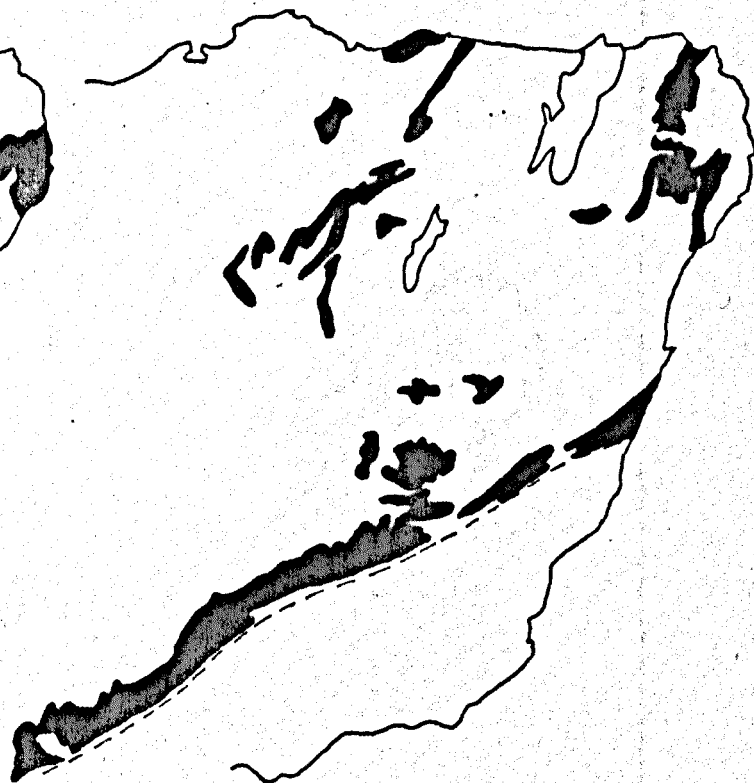


Figure 4.10 Summary of conglomerate composition for the Western Coastal Section.

Granite.



Quartzite and Schistose Grits.



Slate, Phyllite, and Mica Schist.



Banffshire Slate, and Andalusite Schist.

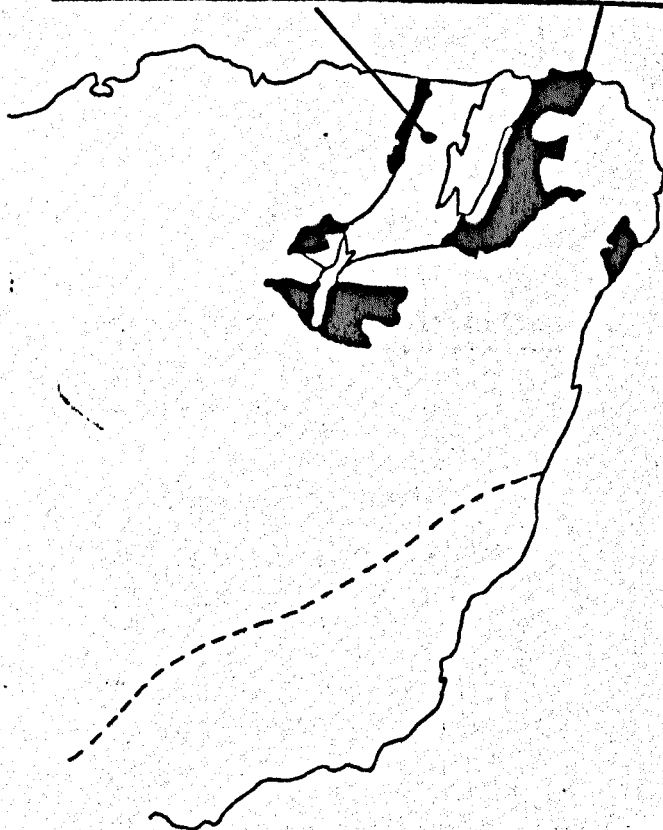


Figure 4.11 Distribution of rock types common to the conglomerates of the study area.

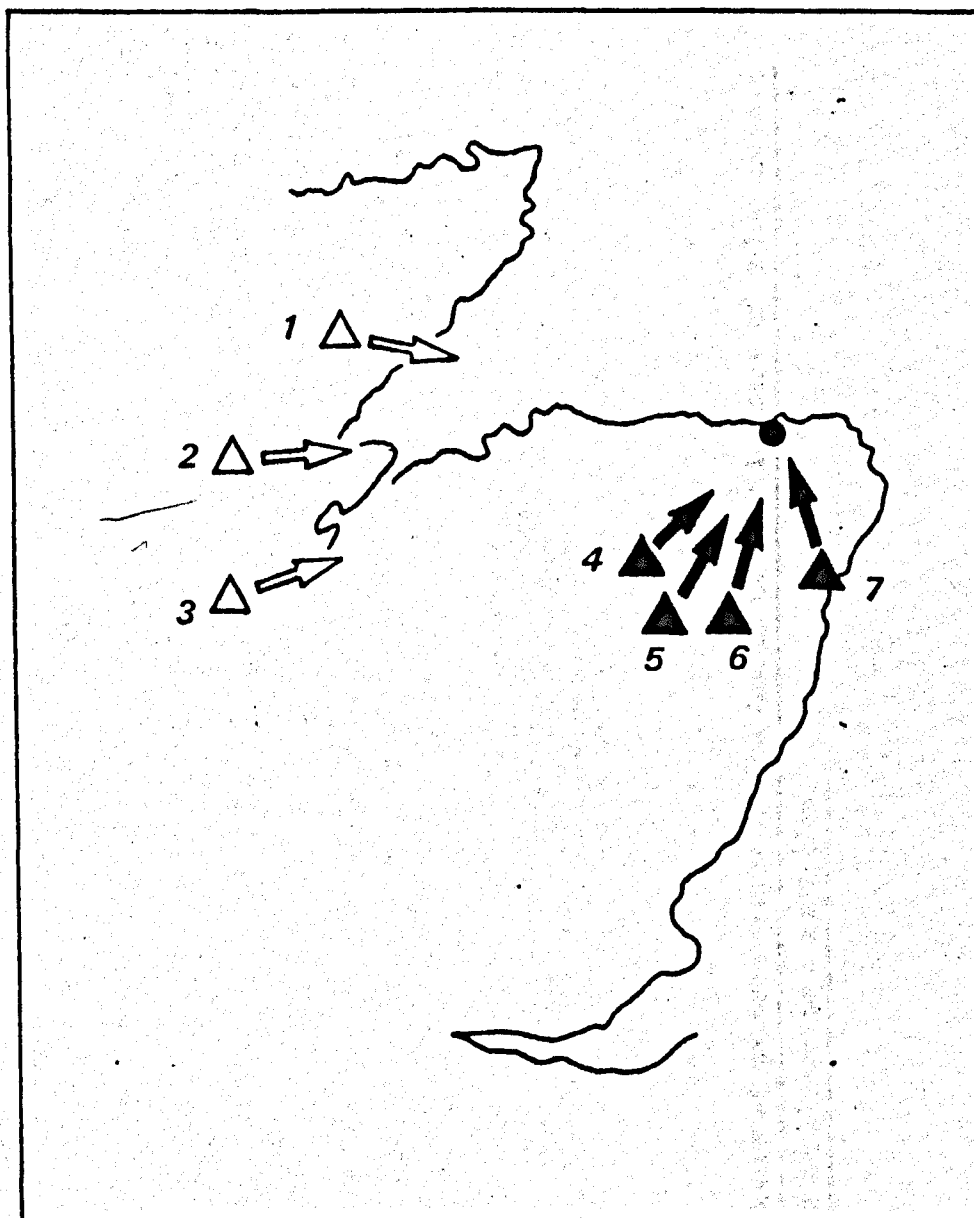


Figure 4.12 Reconstruction of Source Area based on Granite Identification
by Mackie (1923).

Localities:

1. Helmsdale.
2. Inchbrae.
3. Abriachan.
4. Huntly.
5. Correnie.
6. Bennachie.
7. Rubislaw.

(solid arrows represent granites
accepted from present study, open
arrows are those rejected.)

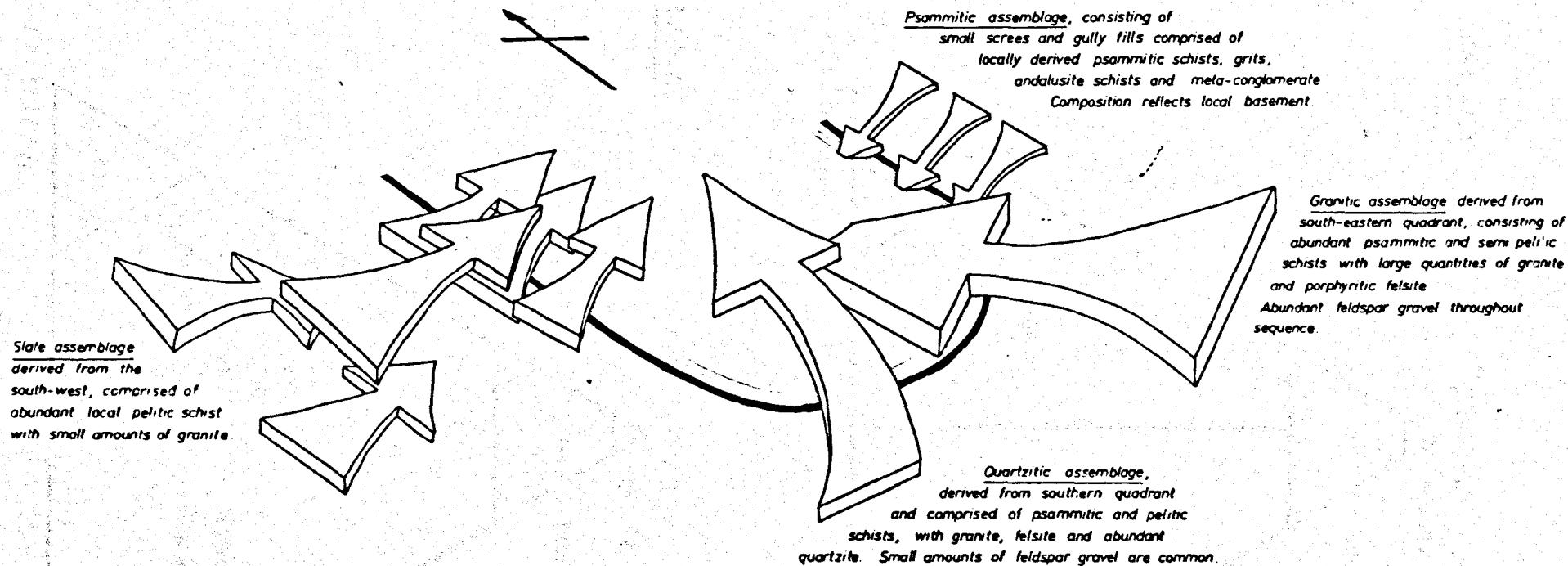
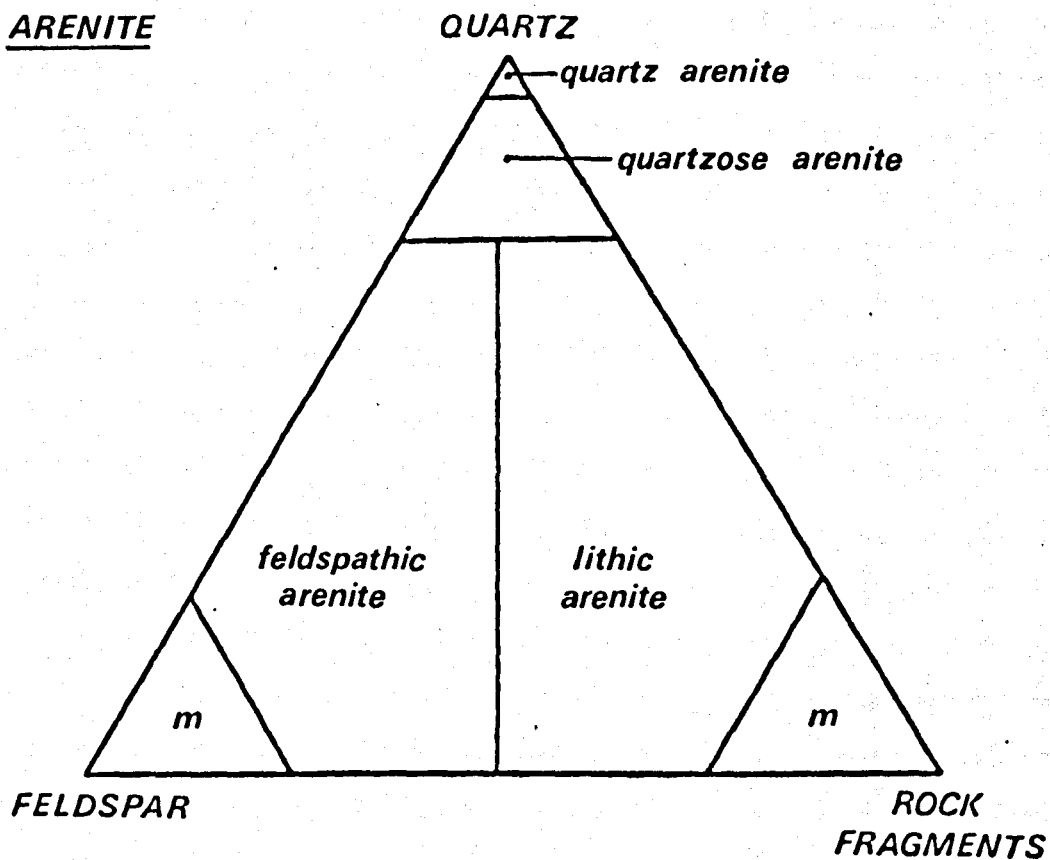


Figure 4.13

Summary of paleogeography of the Gamrie Outlier in terms of paleocurrents and conglomerate composition.

ARENITE



WACKE

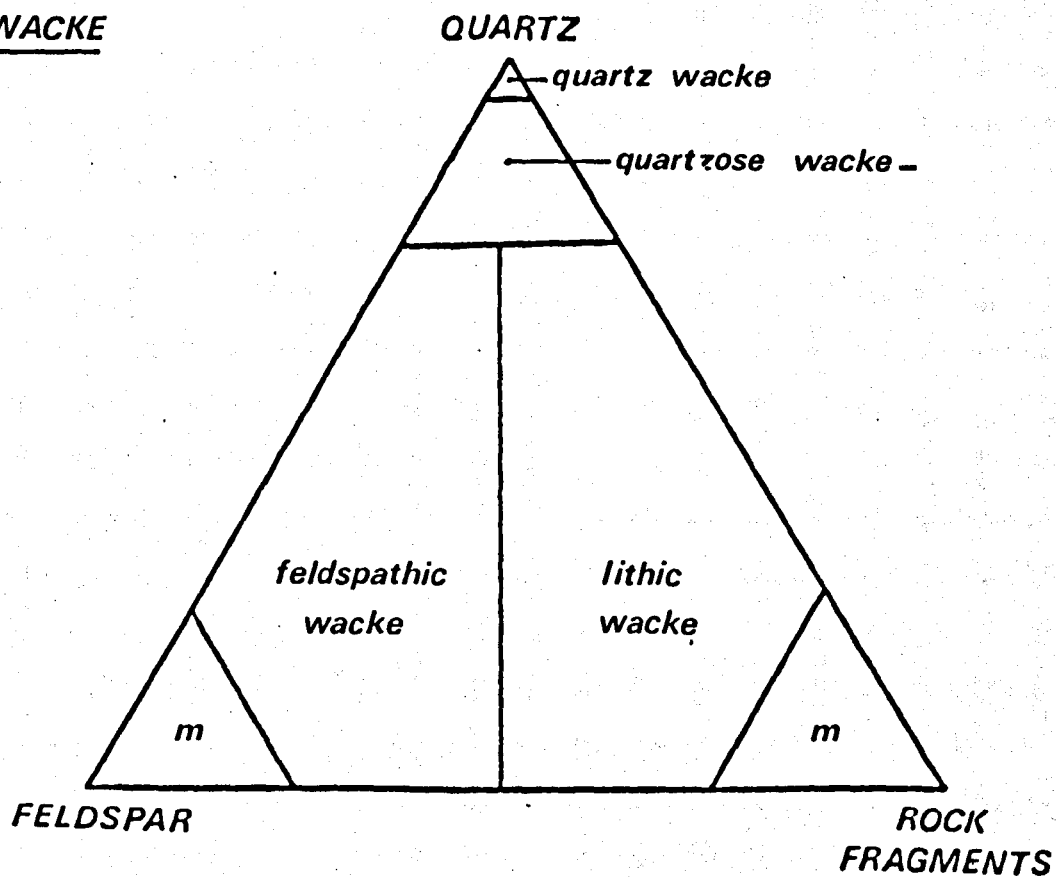


Figure 4.14 Sandstone Classification Scheme (after Okada 1971).

Figure 4.15

Modal analysis of sandstones from the Eastern(A)
and Western (B) Coastal Sections.

(A)

(a)

Quarryhead.

(b)

Dundarg Castle Conglomerate Formation.

(c)

New Aberdour Siltstone Formation.

(B)

(a)

Crovie Sandstone Formation.

(b)

East Harbour Formation.

(c)

Castle Hill Sandstone Formation.

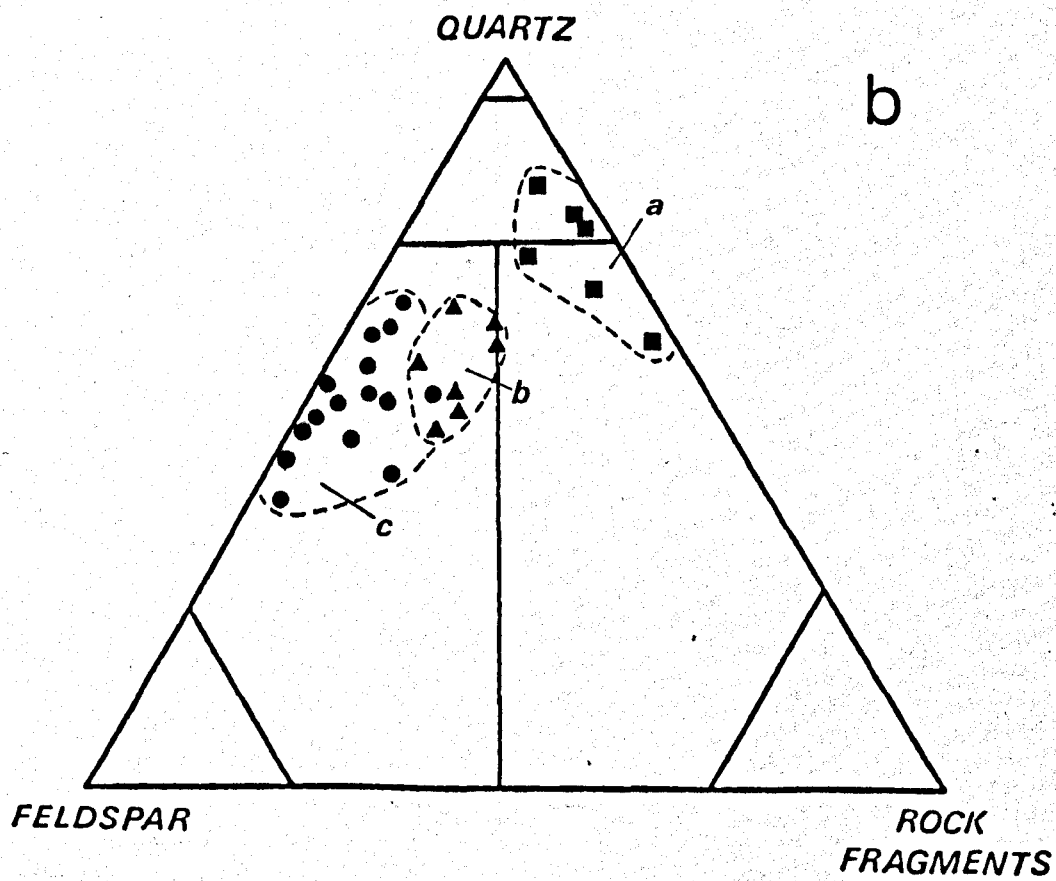
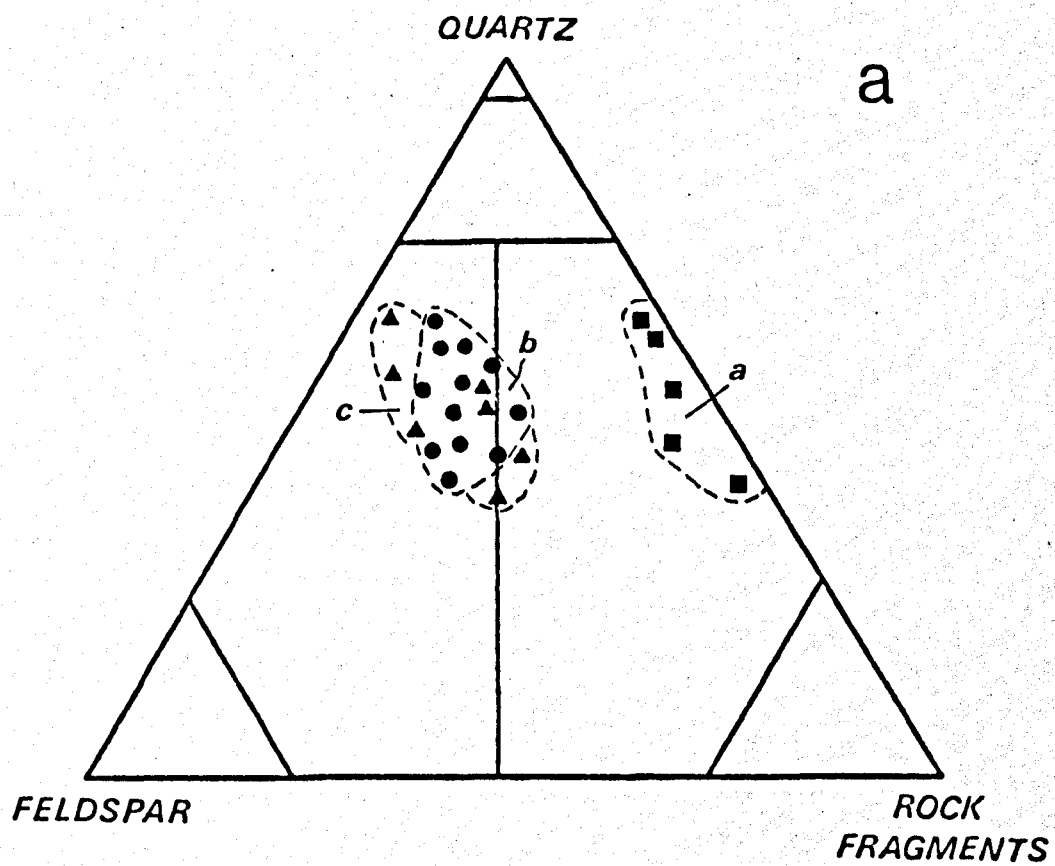


Figure 4.16 (A)

Modal Analysis of sandstones of the
Central Coastal Section.

- (a) Pennan Sandstone.
- (b) Pennan Head Conglomeratic Sandstone.

Figure 4.16 (B)

Effect of grain size on modal composition
of sandstones from the Dundarg Castle
Conglomerate Formation.

● — fine sandstones only

○ — up to granule grade included

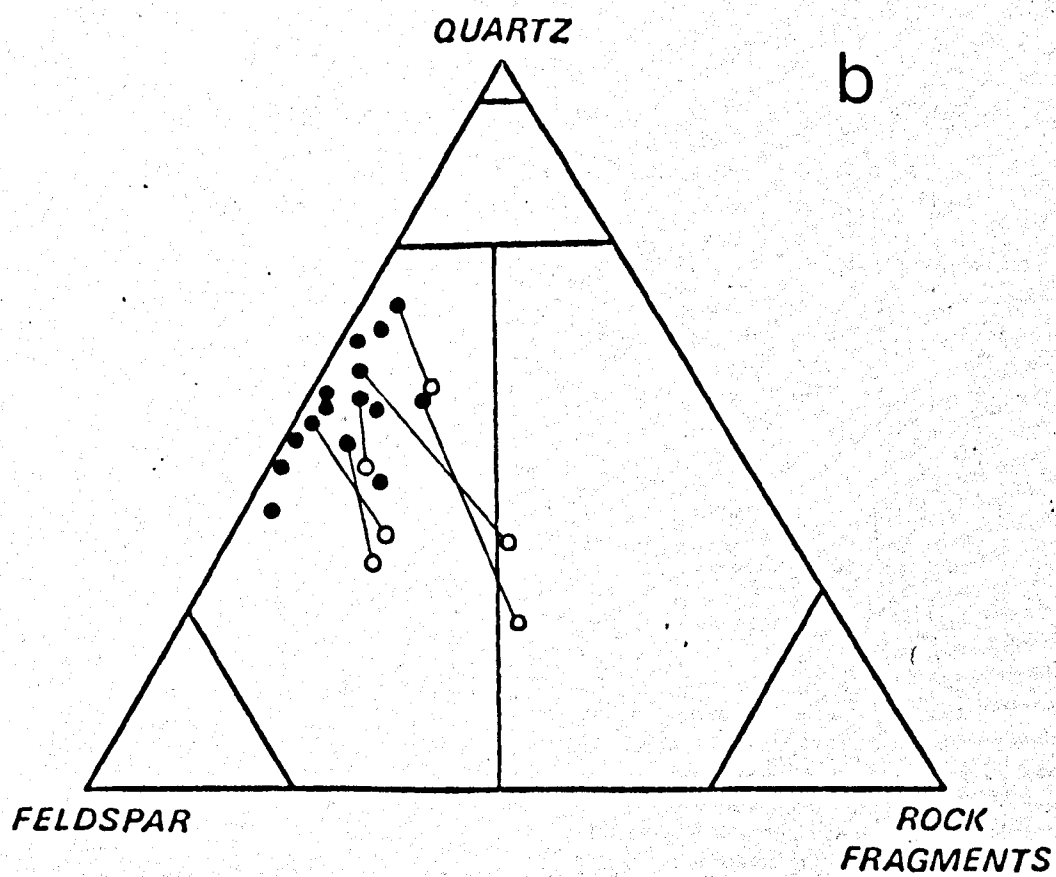
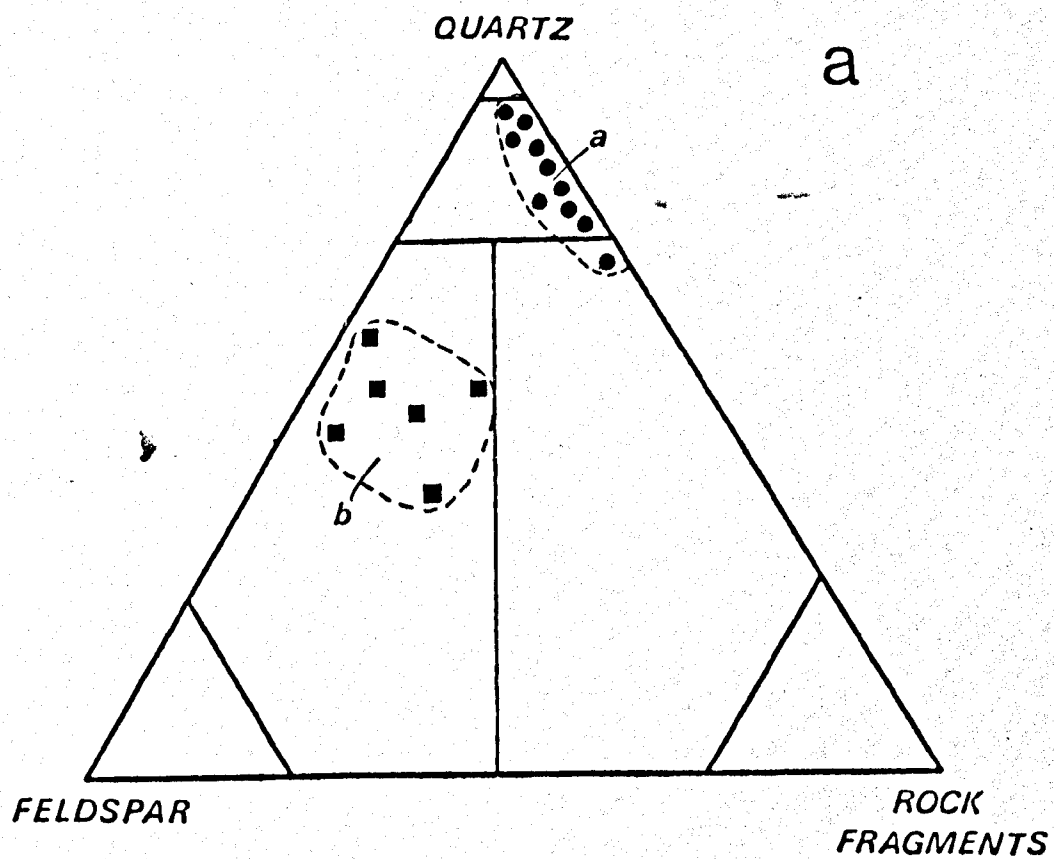


Figure 4.17

Analysis of Quartz type in the Eastern (A)
and Western (B) Coastal Sections.

- (A)
- (a) Quarryhead.
 - (b) Dundarg Castle Conglomerate Formation.
 - (c) Dundarg Castle Sandstone Formation.
 - (d) New Aberdour Siltstone Formation.

- (B)
- (a) Crovie Sandstone Formation.
 - (b) East Harbour Formation.
 - (c) Castle Hill Sandstone Formation.

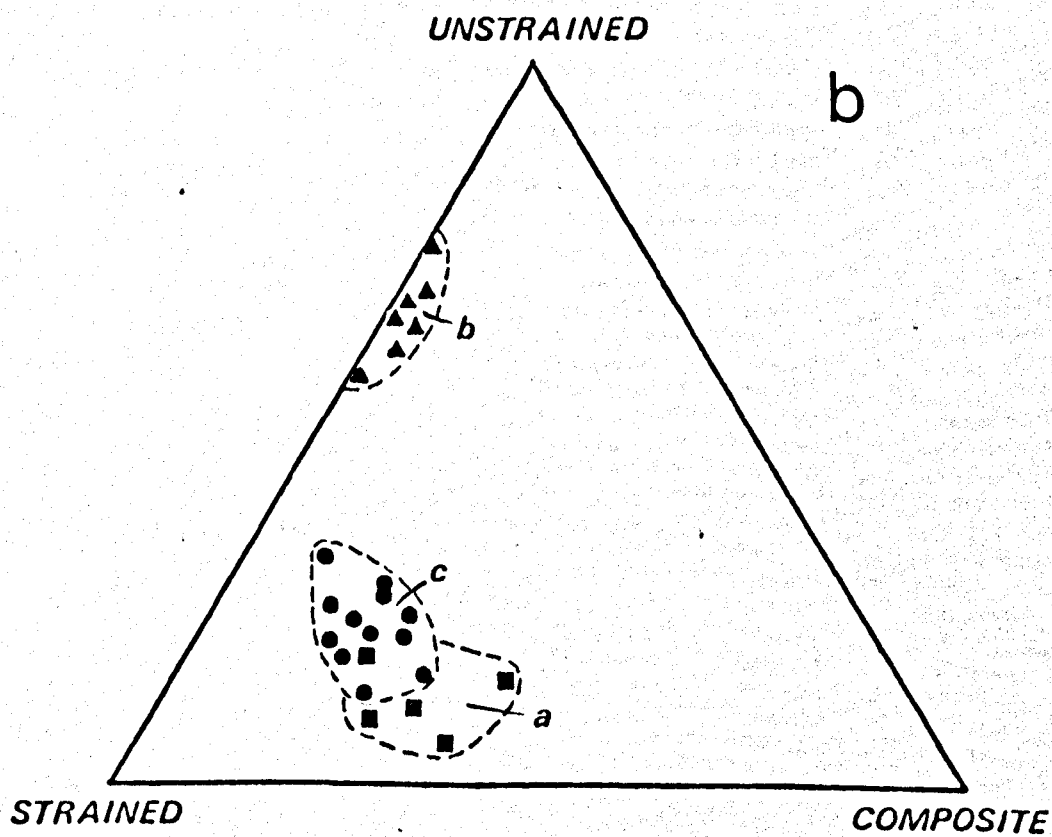
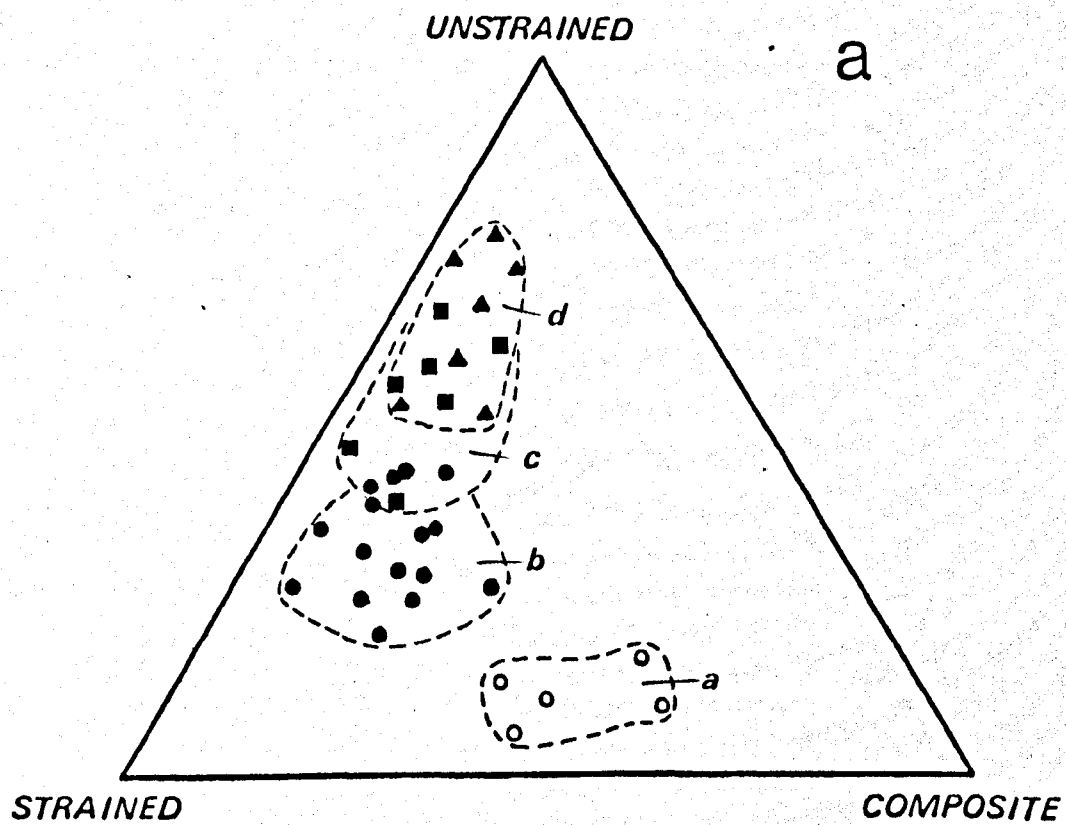


Figure 4.18 (A)

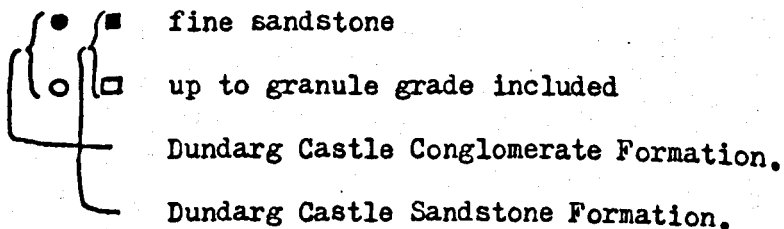
Analysis of Quartz type in sandstones from
the Central Coastal Section.

(a) Pennan Head Conglomerate.

(b) Pennan Sandstone.

Figure 4.18 (B)

Effect of grain size on the abundance of
quartz types.



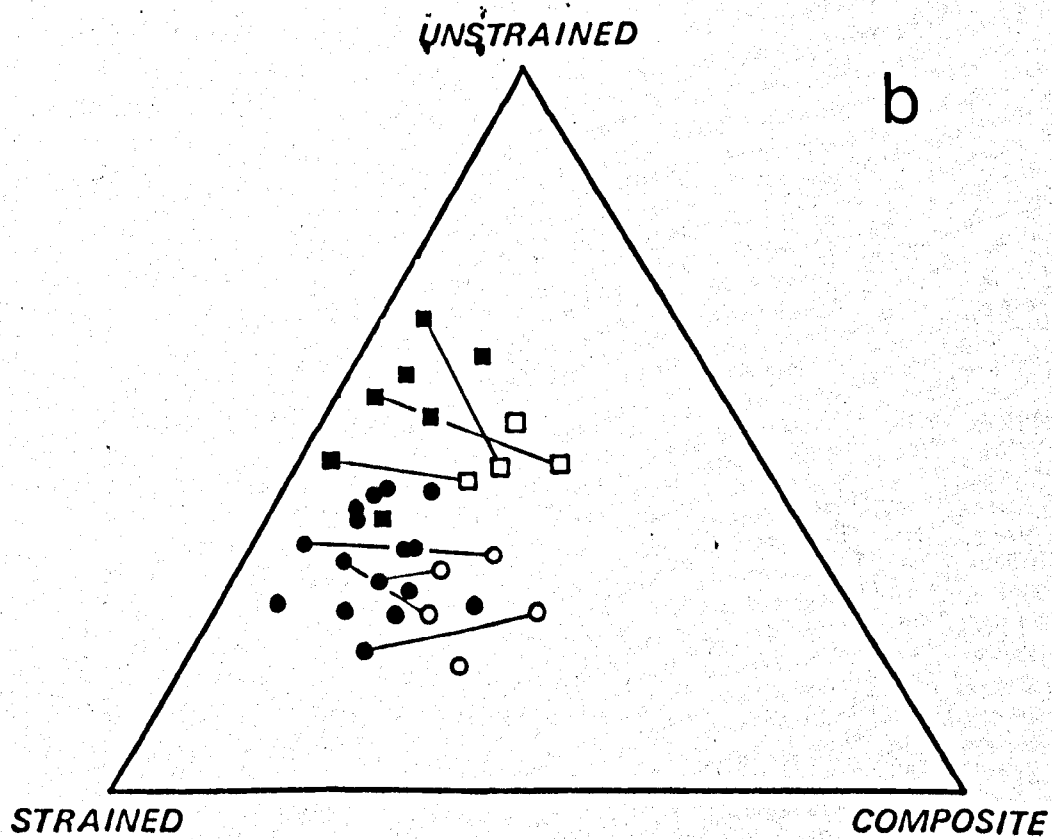
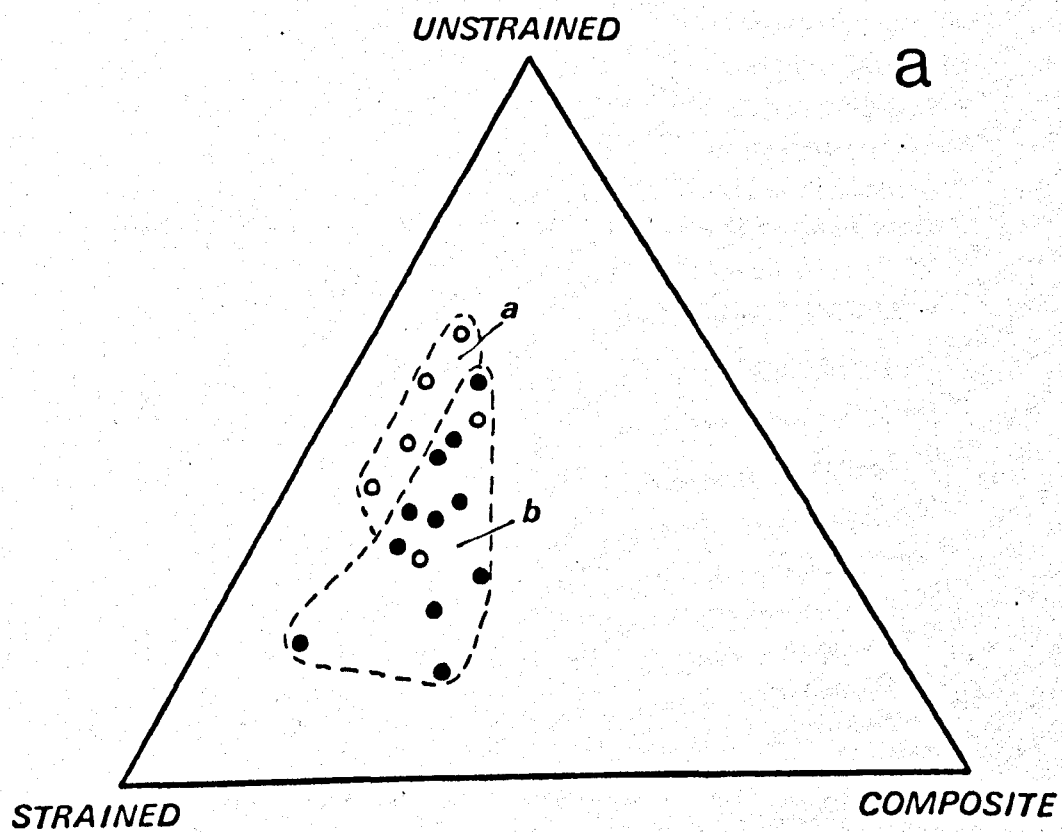


Figure 4.19

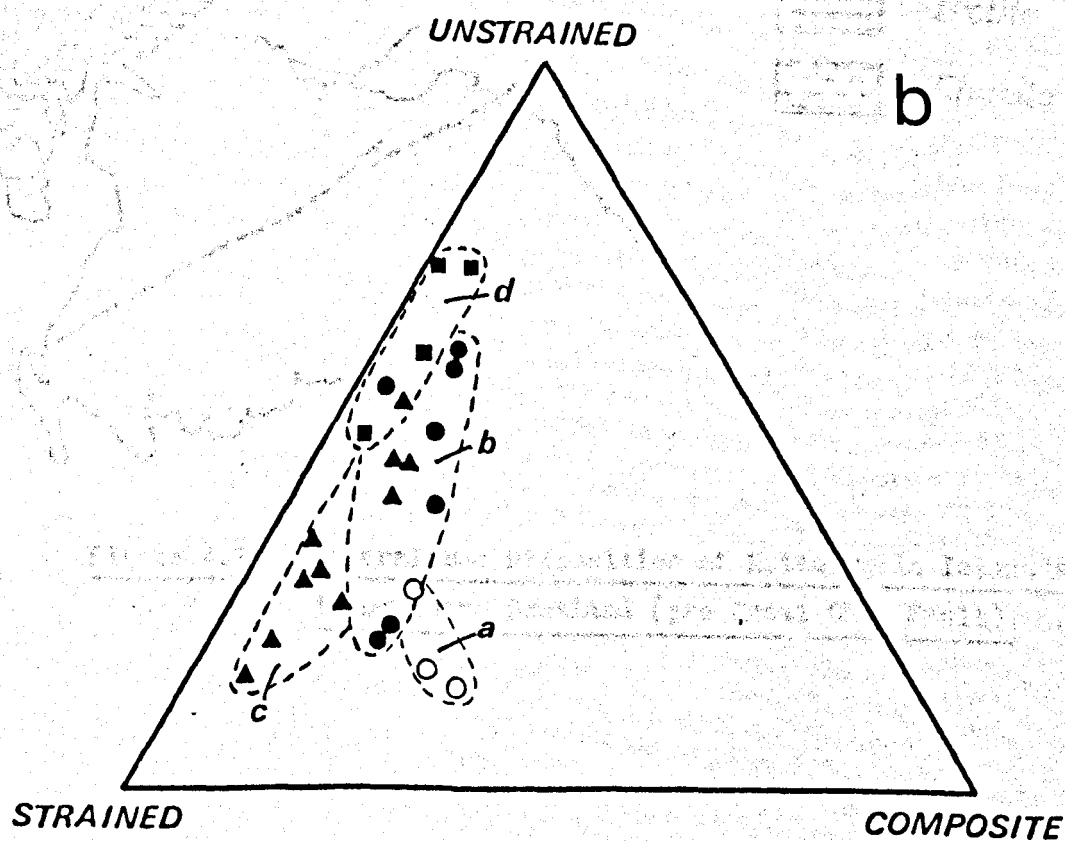
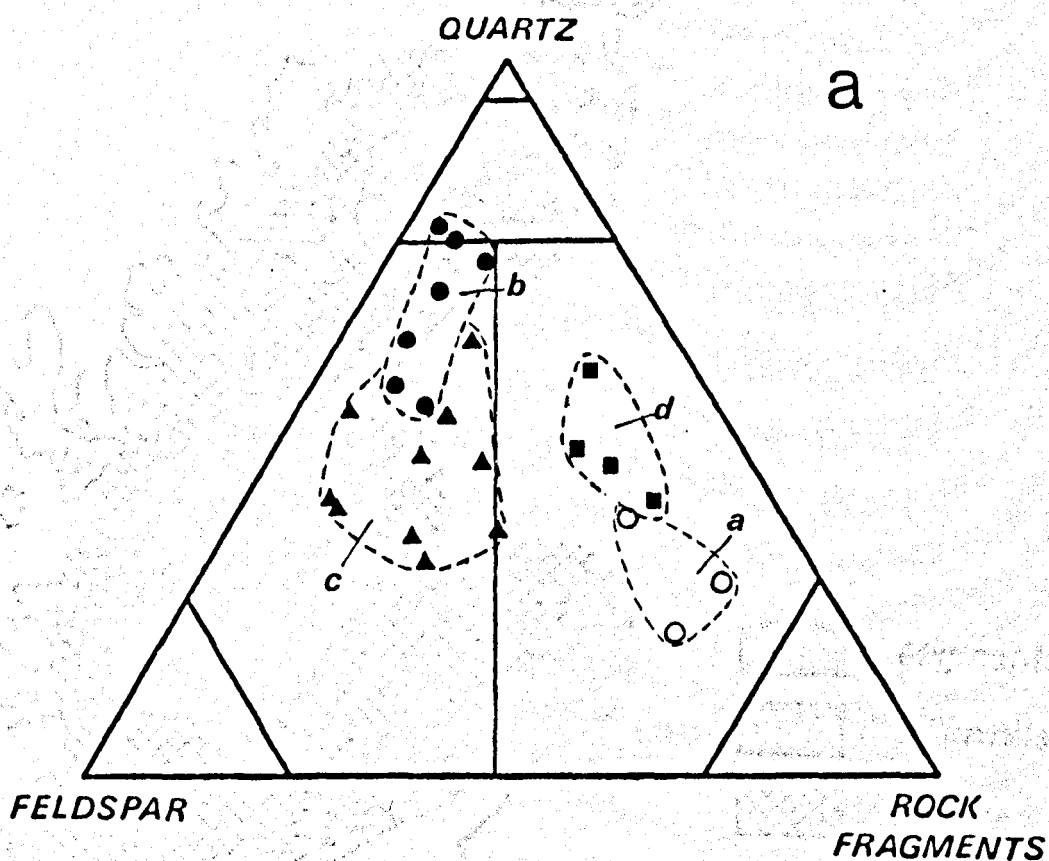
Modal Analysis of sandstones from
the Rhynie Outlier.

- (a) Tillybrachty Sandstones.
- (b) Lower Red Shales.
- (c) Quarryhill Sandstones.
- (d) Dryden Flags.

Figure 4.19 (B)

Analysis of Quartz type in the
sandstones of the Rhynie Outlier.

- (a) Tillybrachty Sandstones.
- (b) Lower Red Shales.
- (c) Quarryhill Sandstones.
- (d) Dryden Flags.



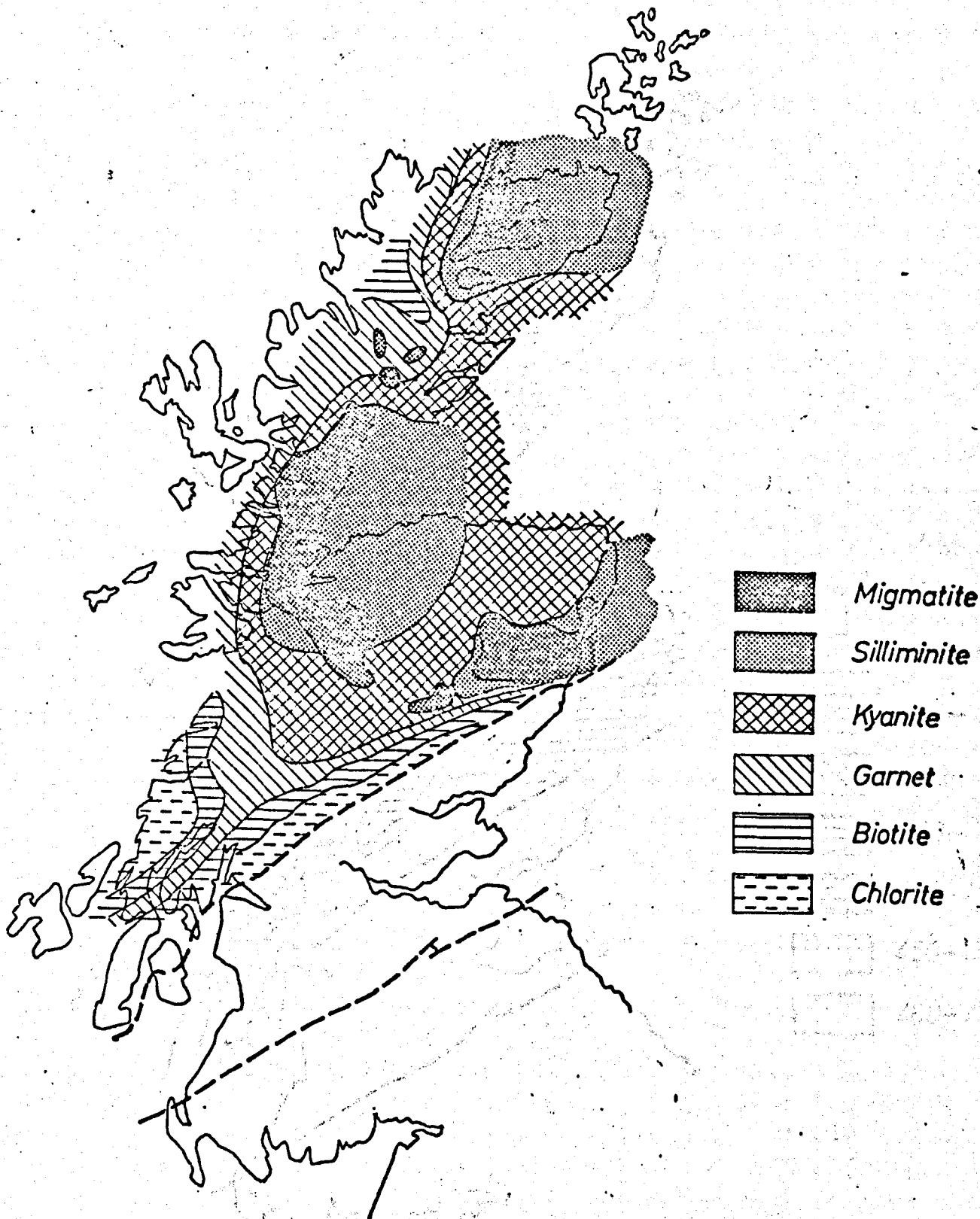


Figure 4.20 Generalised Disposition of Metamorphic Isograds in northern Scotland (pre Great Glen Fault).

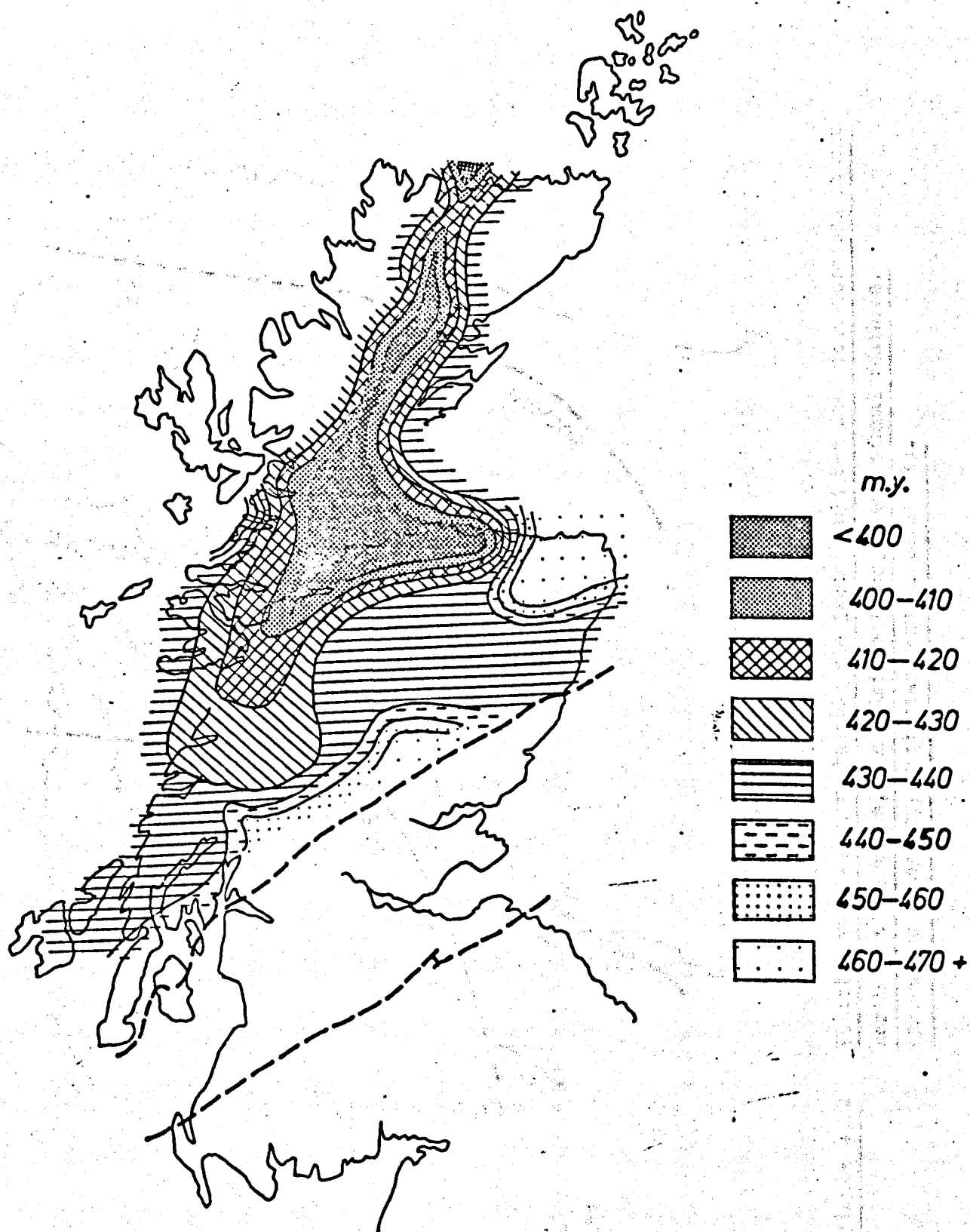


Figure 4.21 A reconstruction of 'chrontours' (potassium-argon age datings of micas) in northern Scotland.

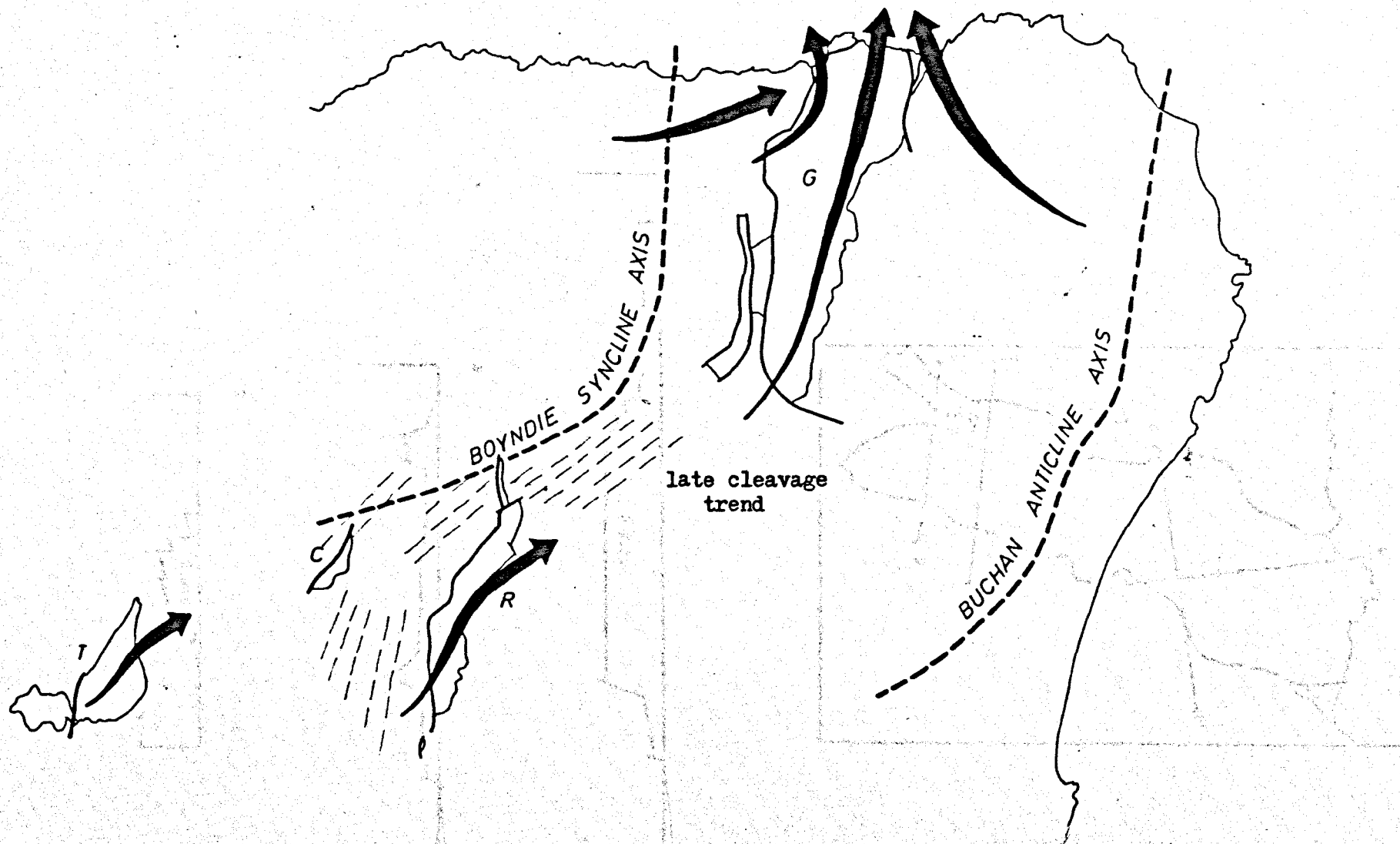


Figure 4.22 . Possible relationships between the isolate Old Red Sandstone Outcrops in the north east Grampians, in relation to major structural features.
(arrows represent apparent transport of sediment).

Figure 4.23 Structural interpretation of the Gamrie Outlier based on
geophysical evidence (after Ashcroft and Wilson 1976).

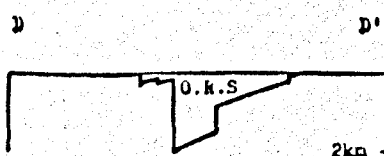
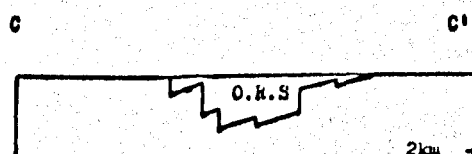
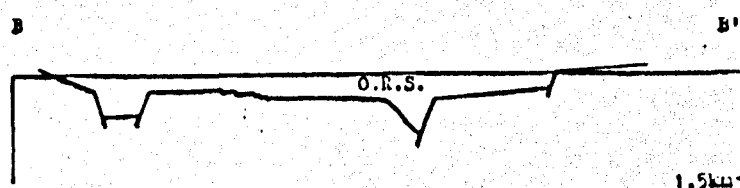
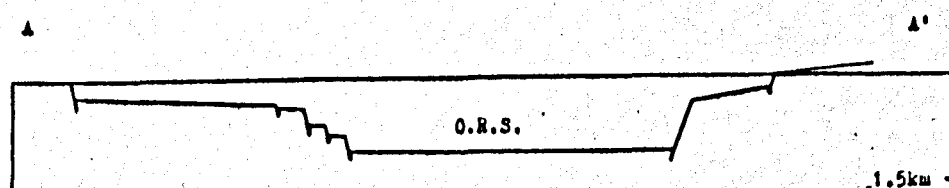
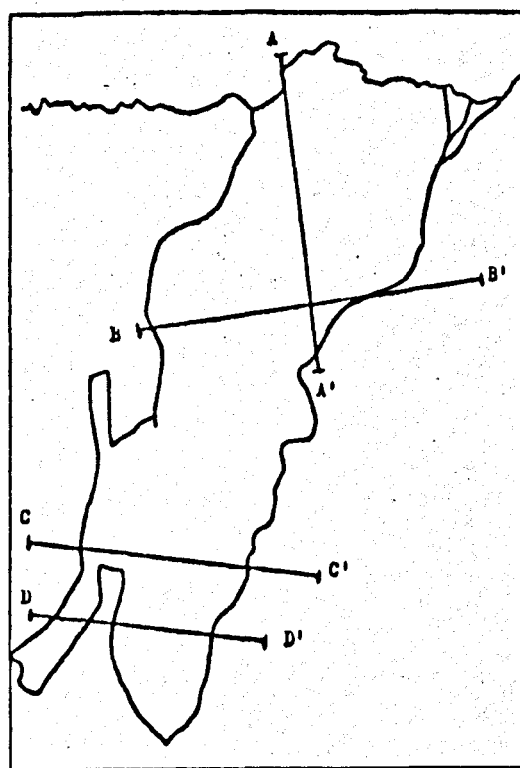
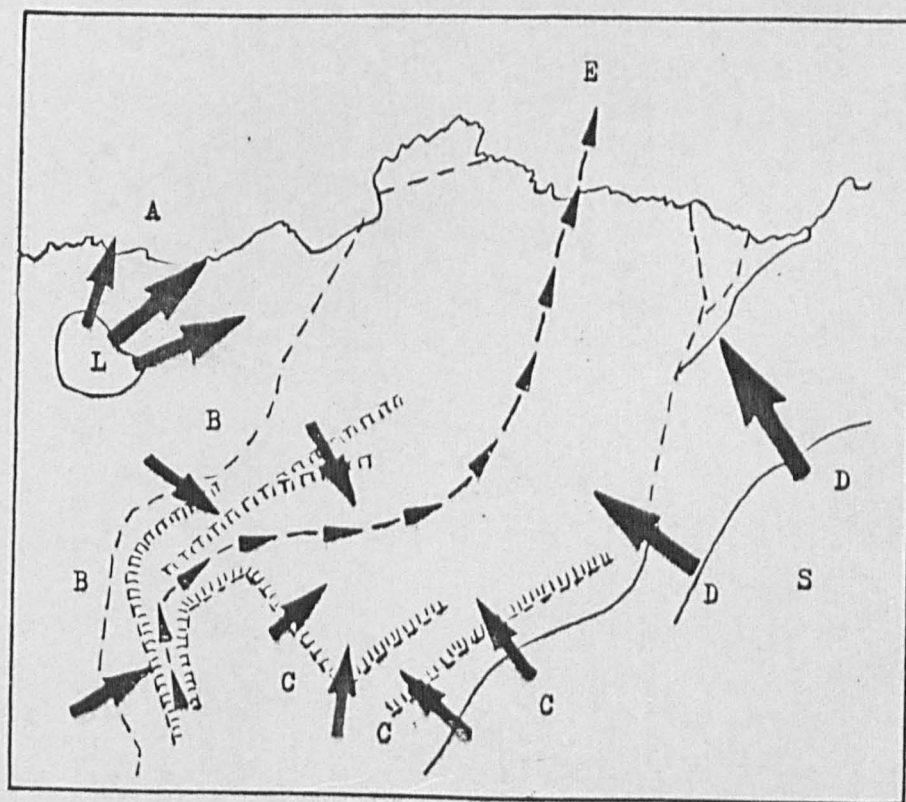
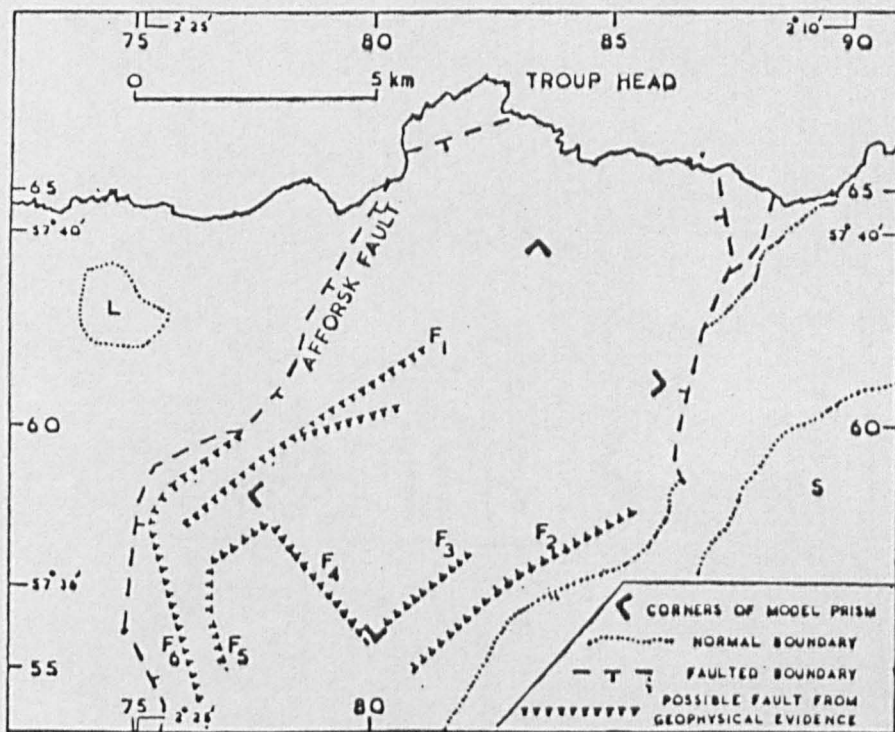


Figure 4.24(A) Detailed interpretation of the form of the basement in the northern part of the Outlier (from Ashcroft and Wilson 1976), showing major fault trends considered to be structural features during deposition of the Old Red Sandstone.

Figure 4.24(B) Detailed reconstruction of possible paleogeography of the northern part of the Outlier employing the above evidence, and incorporating paleocurrent and source rock evidence.

Essentially, the Longmanshill Granite (A) probably a topographic high, provided granite and Banffshire Slate to the Western Coastal Section (A). This same region provided slate detritus to the Quartzite rich assemblage originating south of the area (E), whilst at other times, the Strichen granite to the east provided a granite rich supply of detritus (C). The Strichen Granite could also easily supply the Dundarg Castle Conglomerates with their granite, felsite, and feldspar material.(D)

By this simple model it is therefore possible to provide the granite pebble suite, the slate suite, and more significantly, the mixed assemblage based on quartzite of the Central Coastal Section.



CHAPTER 5

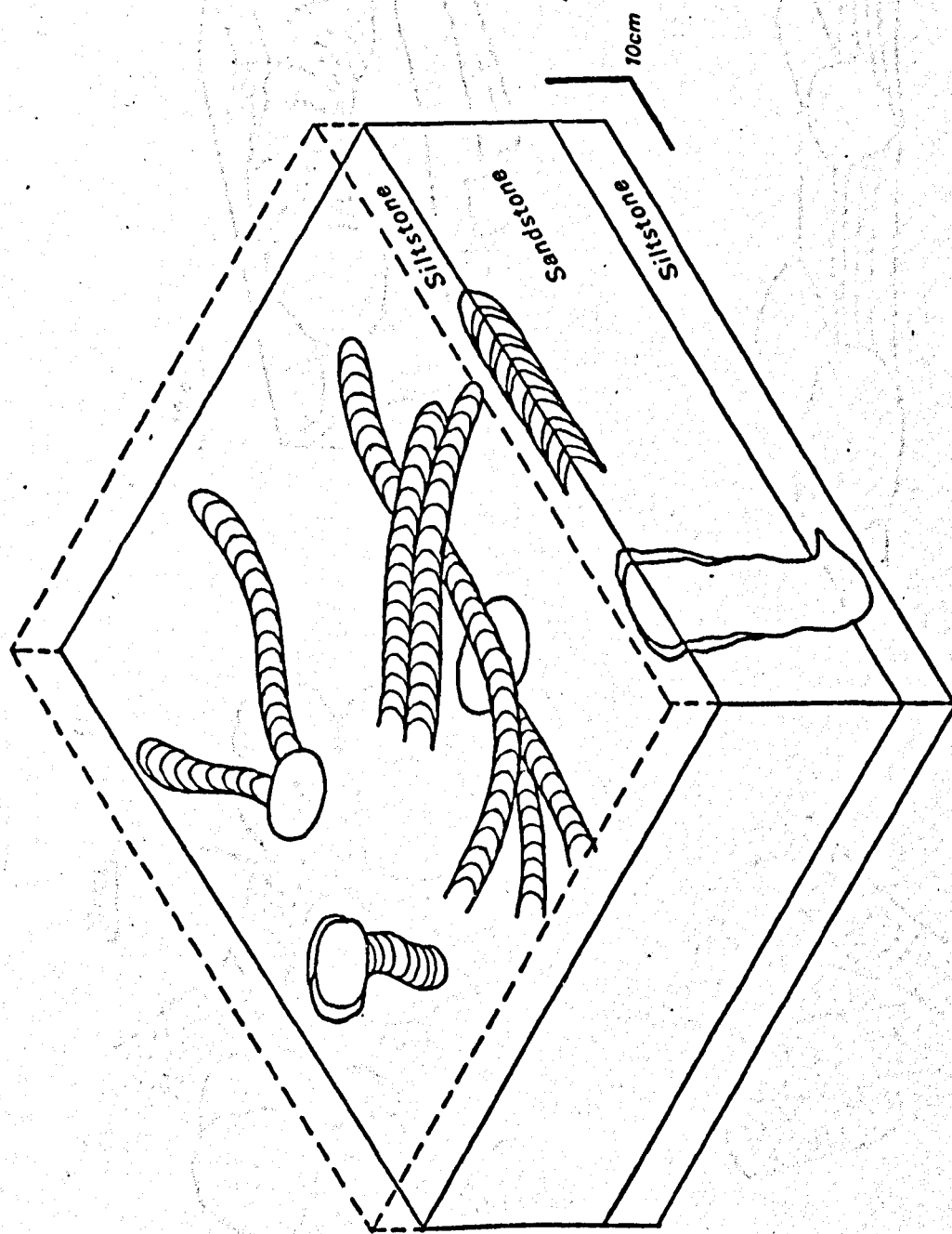


Figure 5.1 Schematic reconstruction of the form and interrelationships of pipes and cylinders based on exposures in the Camrie Outlier.

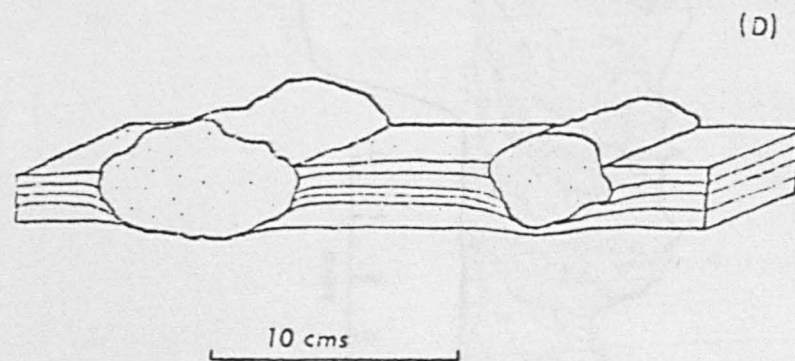
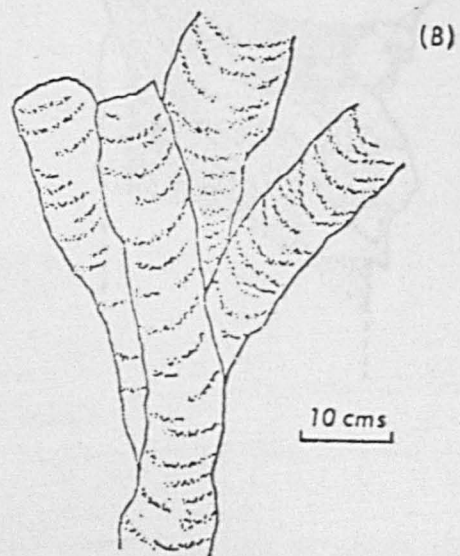
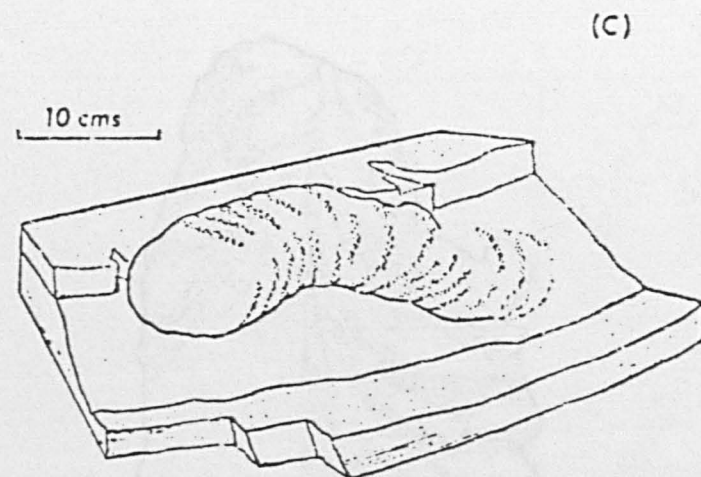
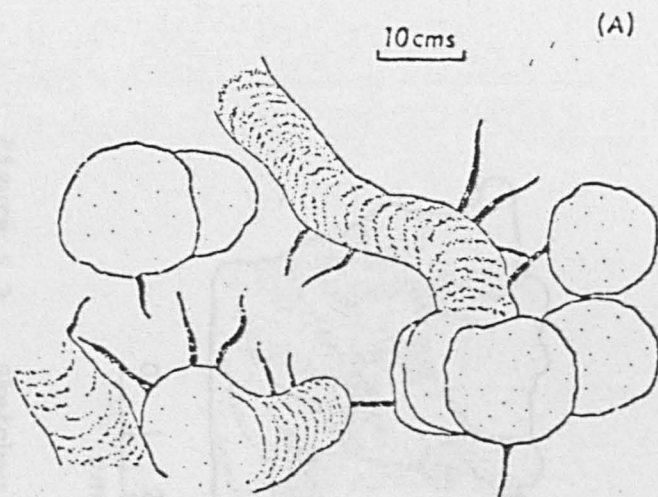


Figure 5.2 Sketches (from photographs) of the form of pipes and cylinders from Counter Head,

a



b

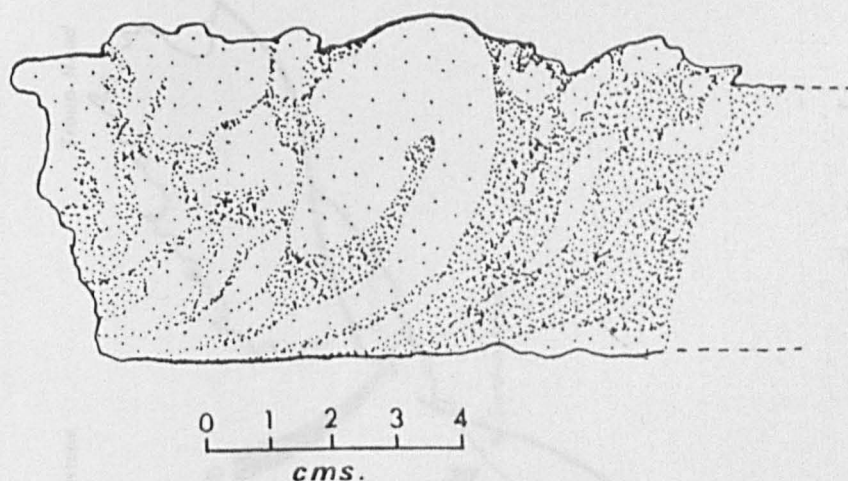


Figure 5.3 Sketches of vertical sections through pipes from
Counter Head showing the relationship between
sandy (light) and silty (dark) pipe infill.

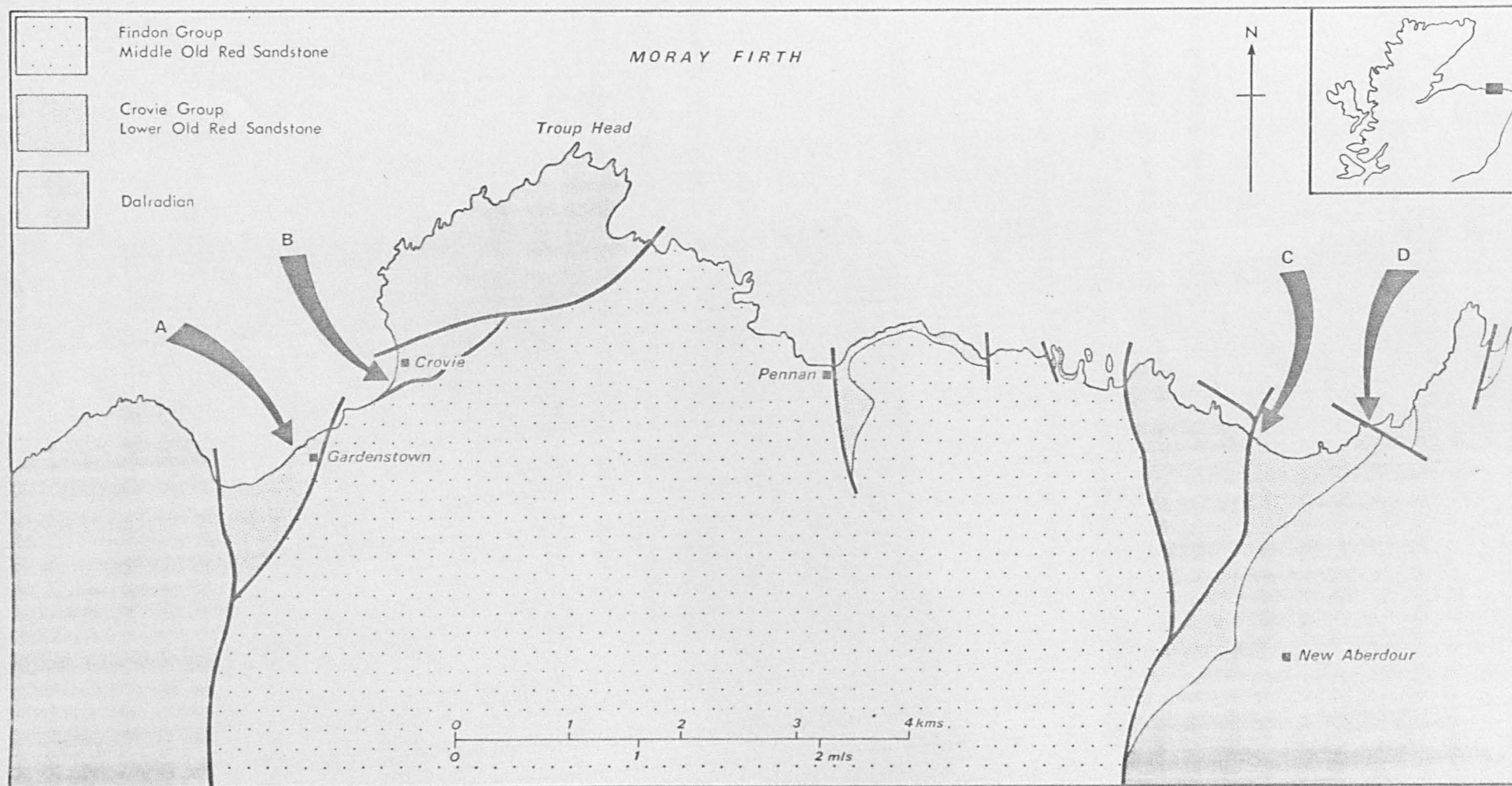


Figure 5.4 Location map of sites within the Gamrie Outlier displaying structures of 'plugged pipe' form.

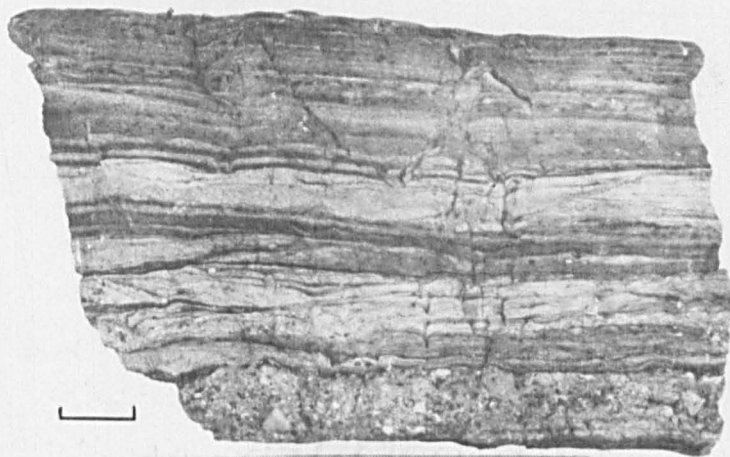
Plate 5.1 Small scale burrows from the Quarryhill Sandstone sequence.

- A. General appearance of the interbedded sandstone and siltstone of the floodplain deposits in which the small scale burrows commonly occur. Small infilled burrows are just visible. (scale: 2cm)

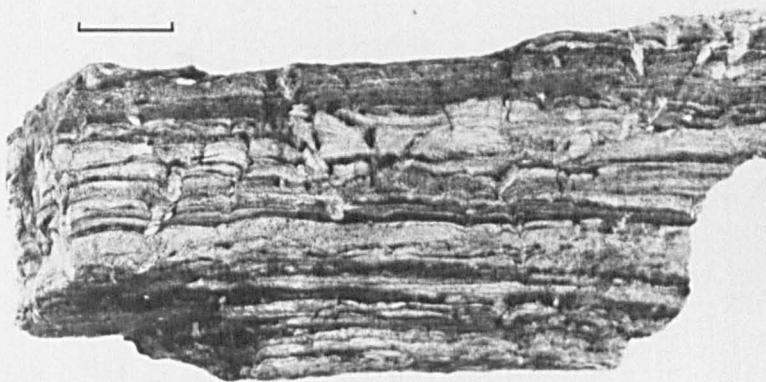
- B. General appearance of floodplain sediment with abundant burrows. (scale:2cm)

- C. Enlargement of portion of above photograph showing detail of burrows. Note the displacive nature of burrows, and the form of the sediment infill.(scale:1cm)

a



b



c

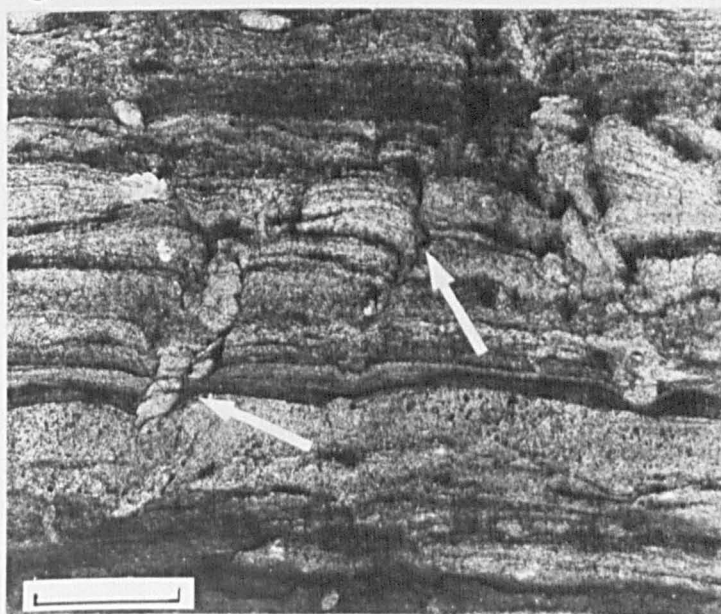


Plate 5.2

Collection of surface markings from within the
Quarryhill Sandstone sequence.

- A. Undersurface, (ie a cast) of the numerous surface impressions found within a thin floodplain sandstone.

- B. Plaster cast from the above specimen showing the true form of the surface markings. Note that many of the markings exist as a strong positive relief. (scale: 2cm)

a



b

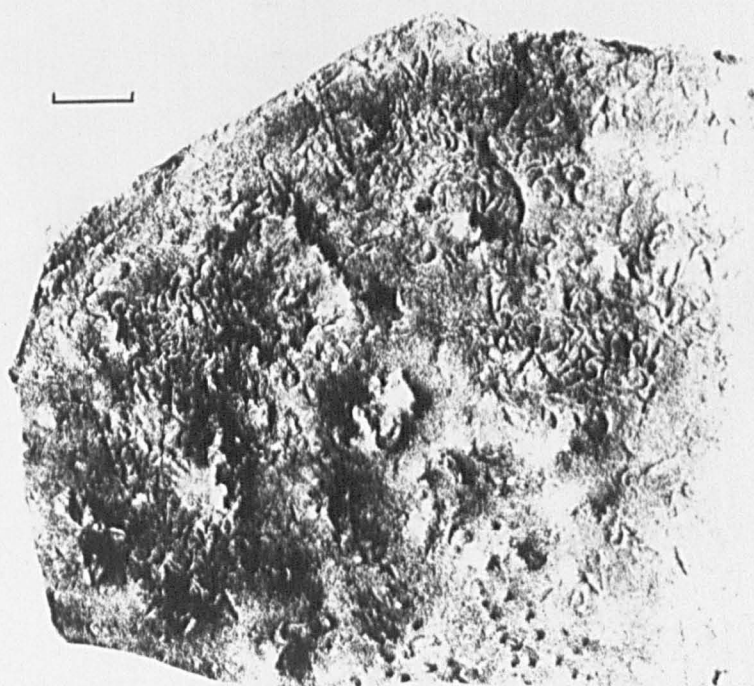


Plate 5.3 Enlargements of portions of the plaster cast
detailed in the previous plate.

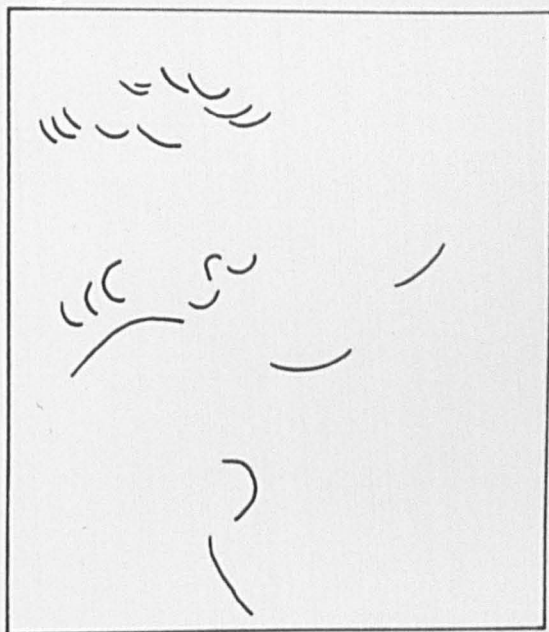
A, C Enlargements of parts of the plaster cast
showing the curved positive relief features
in greater detail. Infilled small scale burrows
are (previously illustrated in plate 5.1) arrowed.
(scale:2cm)

B, D Sketches from the above plates showing possible
relationships between series of curved traces,
and suggesting a possible genetic relationship.

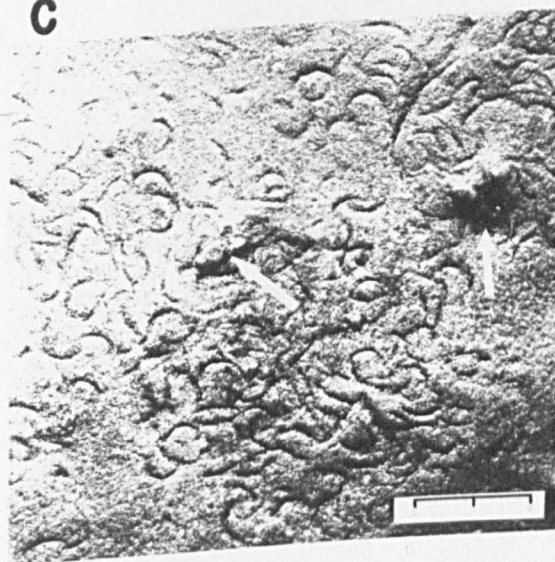
a



b



c



d

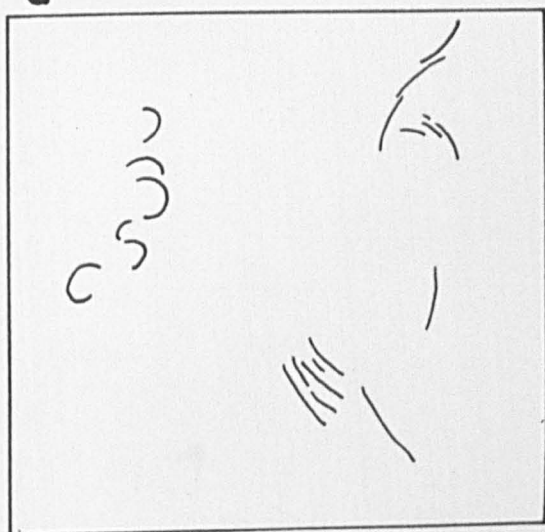


Plate 5.4 Experimentally produced surface features
comparable to those illustrated in plates 5.2, 3.

Plates A and B show the results of the total desiccation of an originally photosynthesising algal layer. The scale bar in both instances represents 1 cm.

Note the similar shape and form of the positive relief features, and also the similar range of shapes and sizes produced.

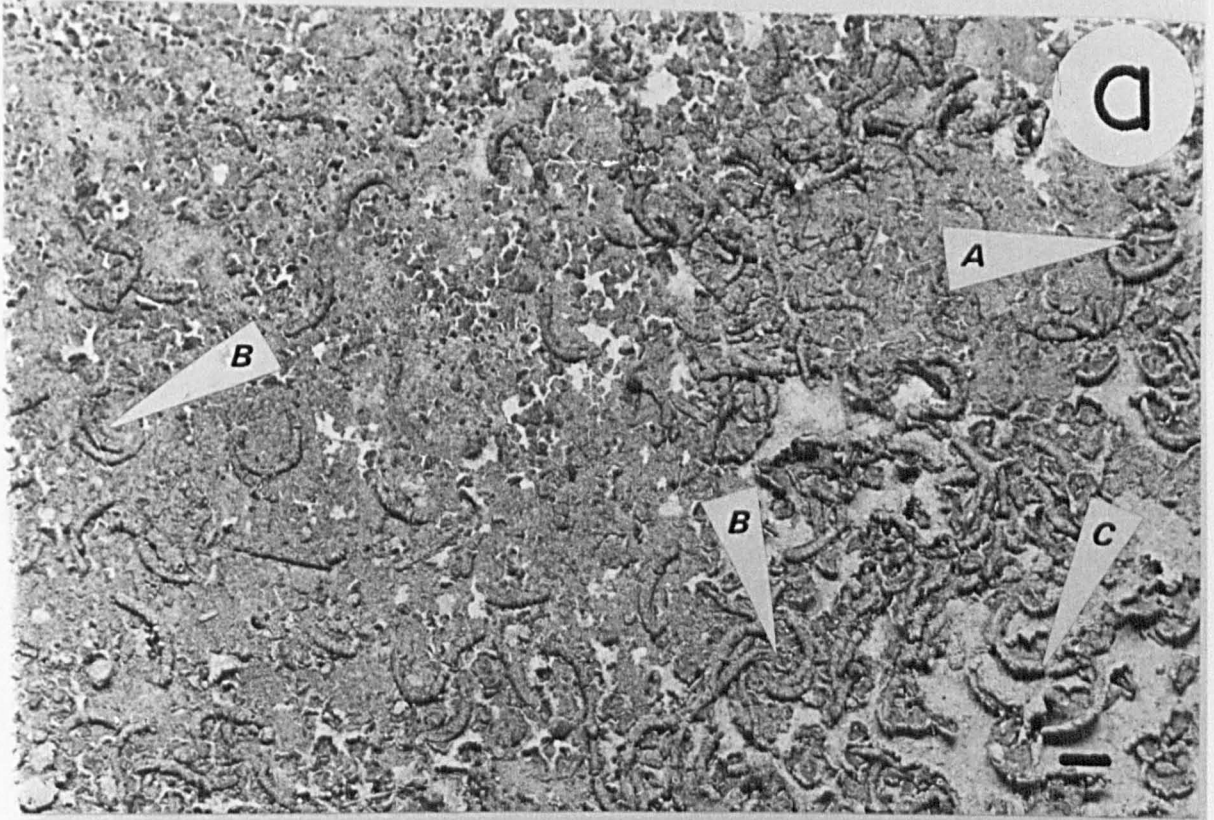


Plate 5.5 Smooth surface trail from within the Quarryhill
Sandstone sequence.

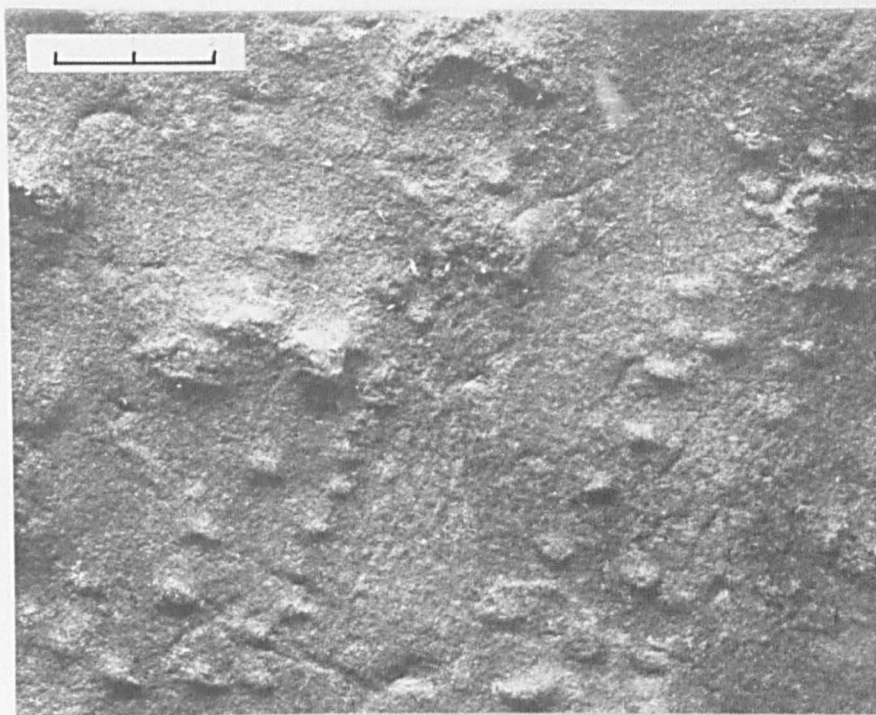
Smooth trail preserved within floodplain
sandstone, as a thin film of red mud.
(scale: field width 10 cm)



Plate 5.6 Sharp surface impressions, Quarryhill Sandstone.

- A. General form of surface impressions as found
on the undersurface of a floodplain sandstone
unit within the Quarryhill Sandstone sequence.
(scale: 2cm)
- B. Plaster cast of the above area, showing the 'true'
form of the traces. Note the paired, parallel
series of simple depressions probably corresponding
to walking trails.
(scale: 2cm)

a



b

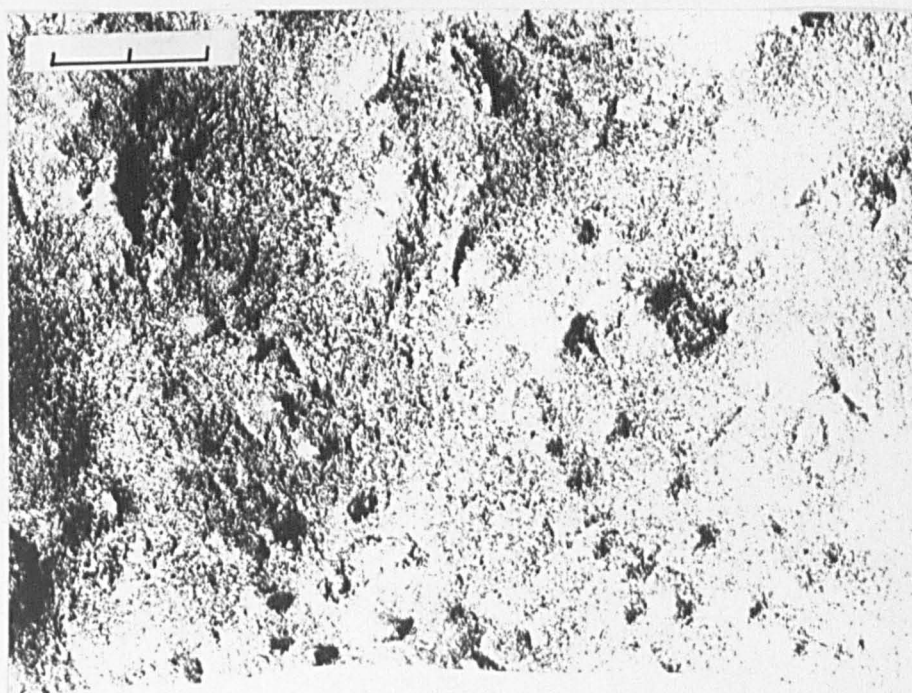
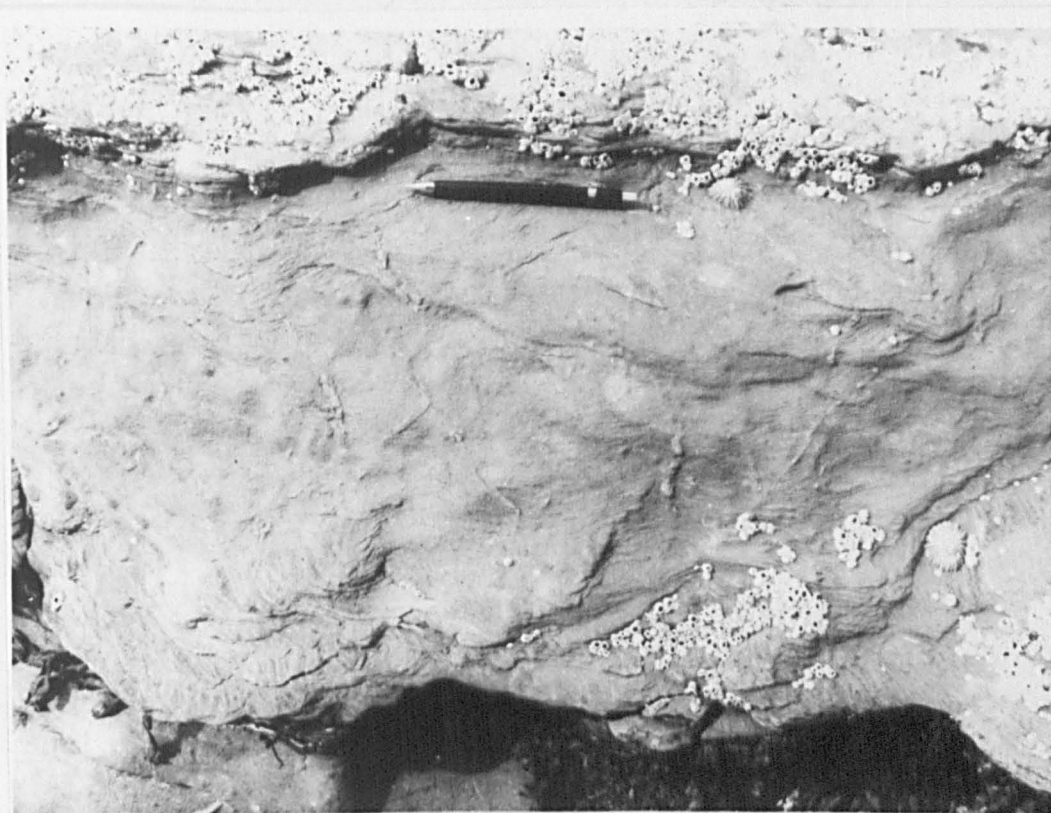


Plate 5.7

- A. Small mud-filled burrows within floodplain sediments in the West Harbour Formation at Gardenstown.

- B. Undersurface of sandstone unit in the Quarryhill Sandstone sequence showing probable plant stems.
(scale: 10 cm)

a



b

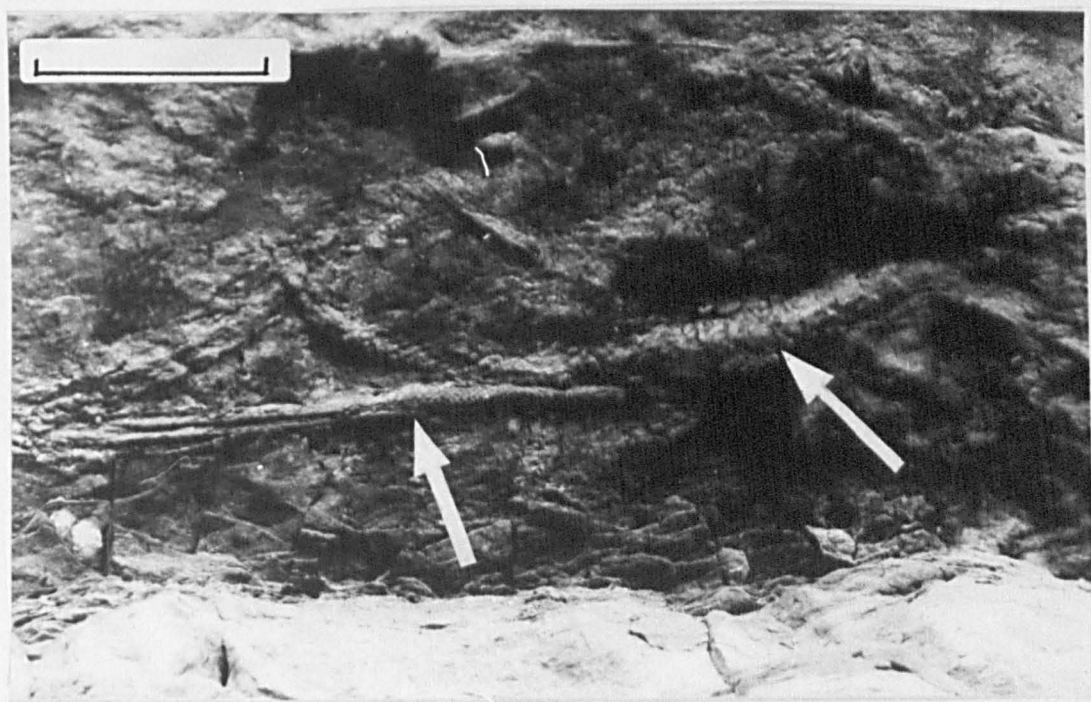


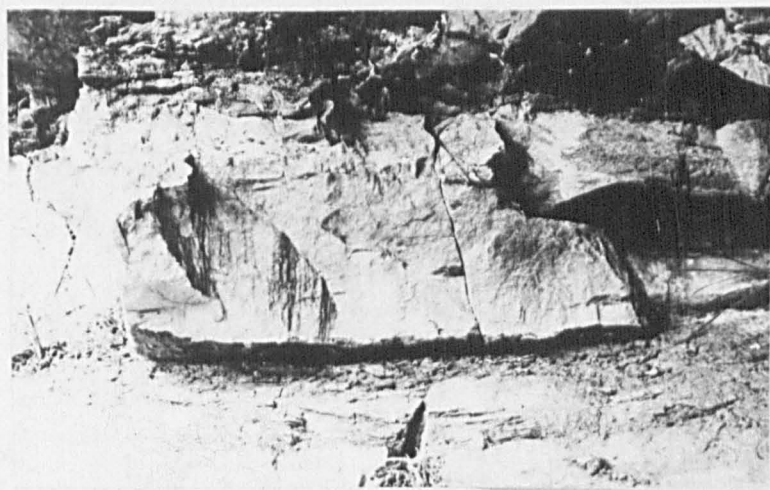
Plate 5.8 Mud-filled tubes from within the Quarryhill Sandstone sequence.

- A. General form and extent of mud-filled tubes, here shown almost traversing a thick, massive sandstone unit. (scale: field width 5m)

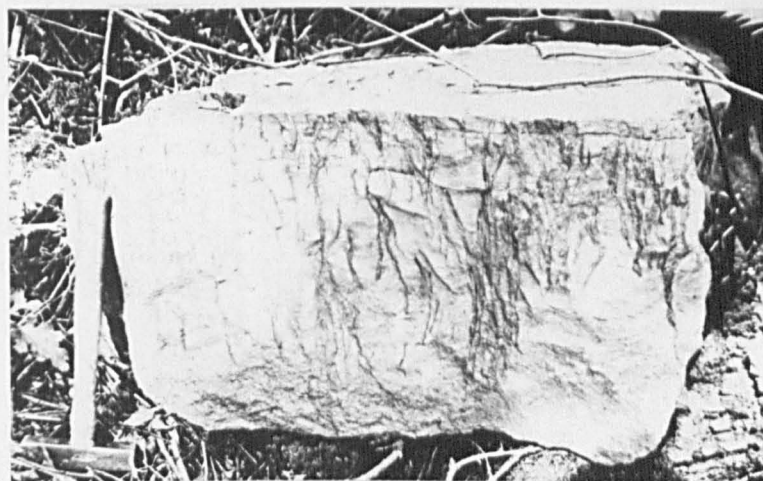
- B. Detailed view of mud-filled tubes showing thin slender nature of tubes, and common intertwining appearance.

- C. View of mud-filled tubes on bedding plane surface showing sections of tubes as small circular pits.

a



b



c

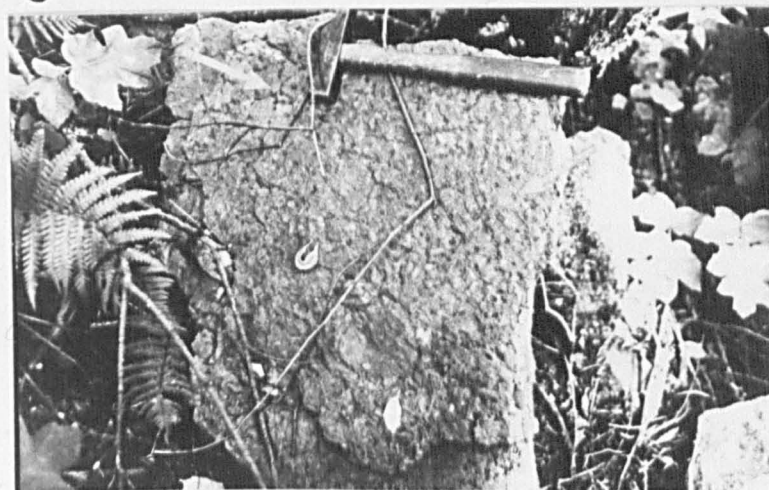


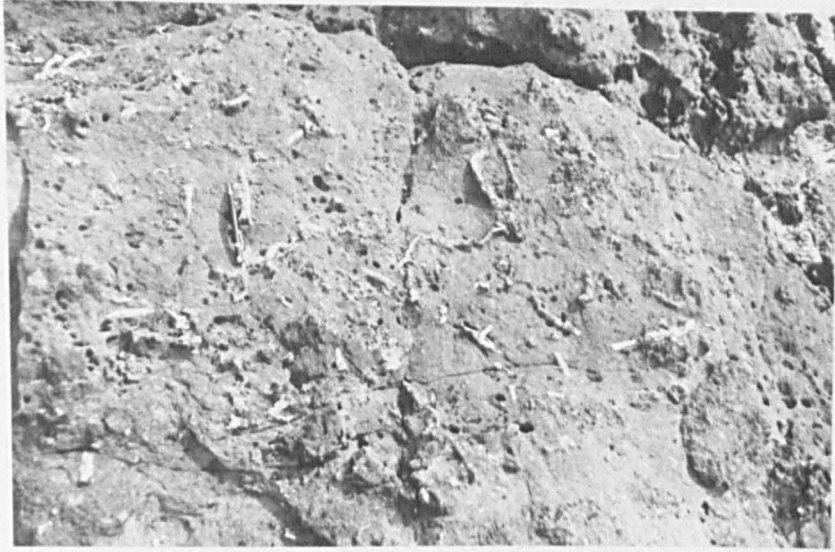
Plate 5.9 Carbonate filled tubes, Quarryhead.

A series of plates demonstrating the general form and appearance of the carbonate filled tubes found within the lowest sediments at Quarryhead.

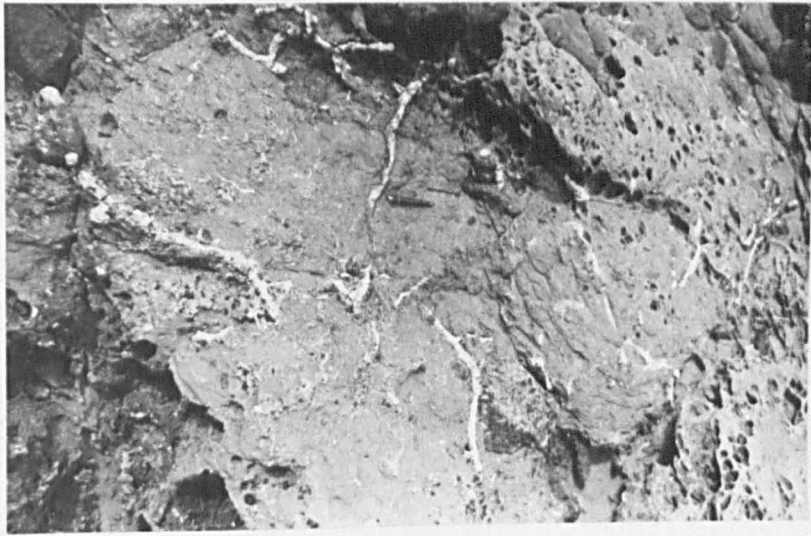
Note the general consistency of size, the repeated branching, and that the tubes appear unrelated to bedding surfaces.

The scale is indicated by a pencil in the upper two photographs, the field width is 40 cm in the lower view.

a



b



c

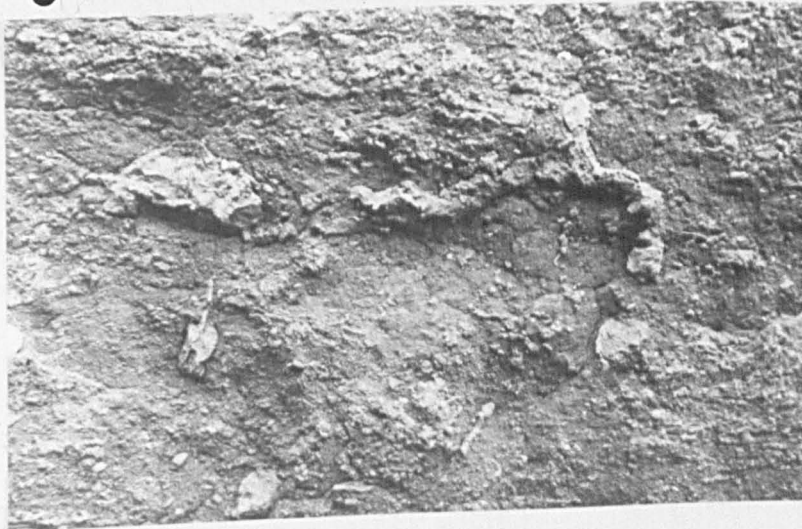


Plate 5.10 Carbonate filled tubes, Quarryhead.

Carbonate filled tubes, Quarryhead.

- A. Further view of carbonate filled tubes, showing related smaller scale structures.
(hammer marked in 10 cm intervals)
- B. Detail of a carbonate filled tube showing the presence of a hollow core.
(coin for scale approx. 3cm)

a



b



CHAPTER 6

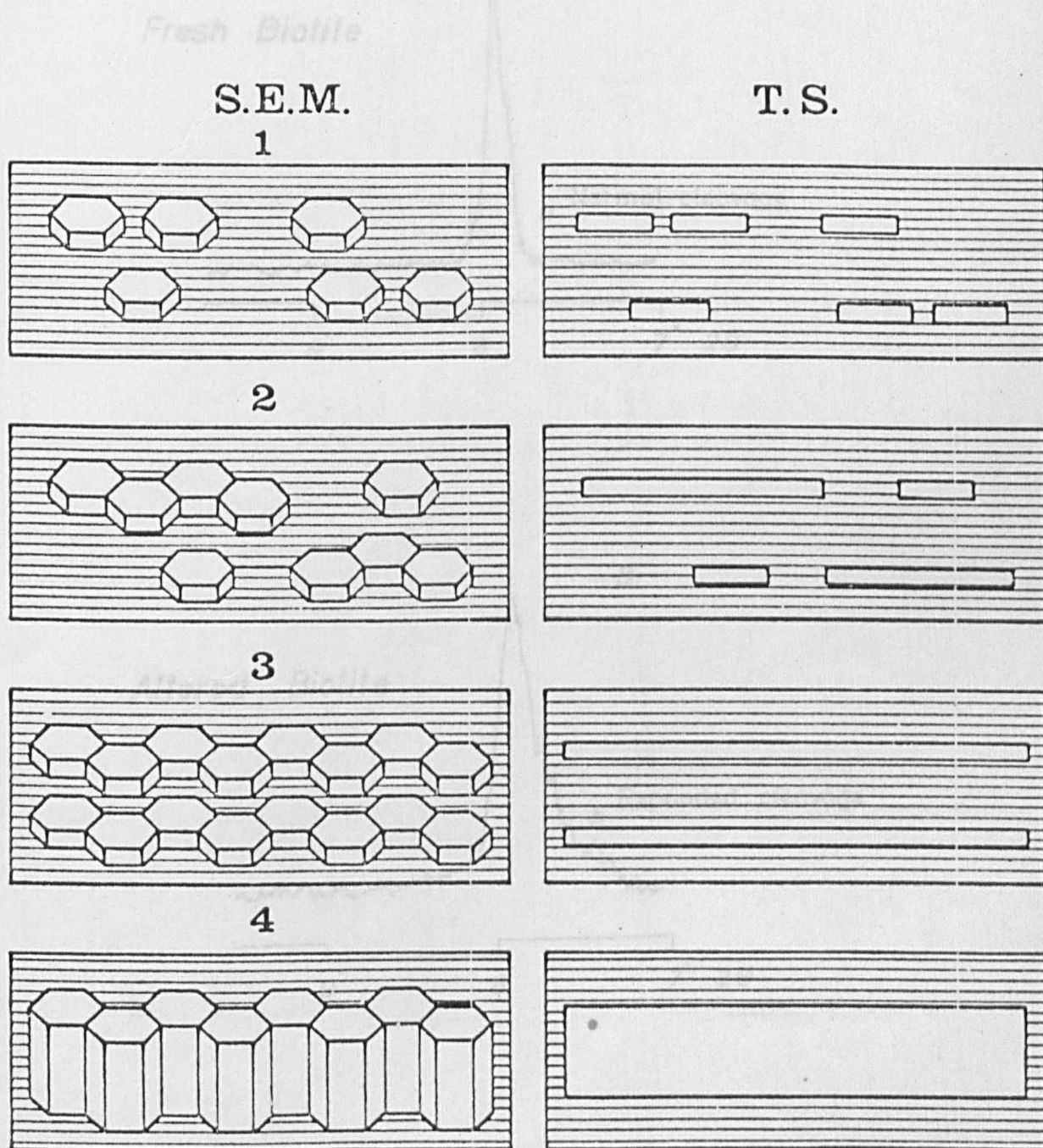
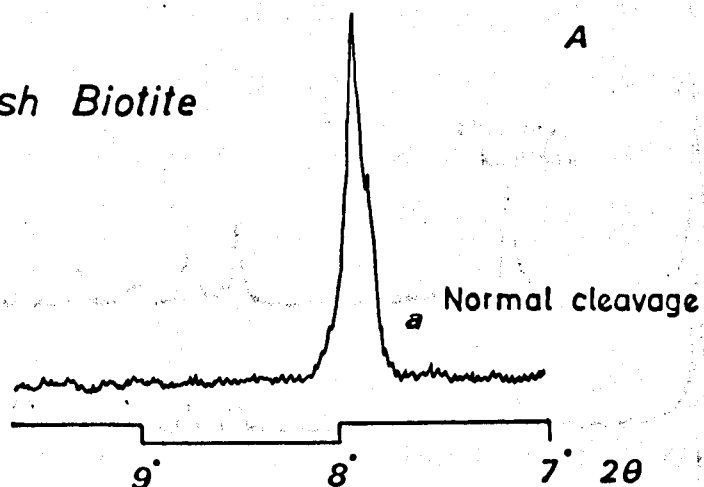


Figure 6.1

Schematic reconstruction of hematite development in biotite flakes combining evidence from Scanning Electron Microscopy (S.E.M.) and Thin Sections (T.S.).

1. development of isolate hematite flakes
2. coalescing of hematite flakes
3. formation of sheets of hematite flakes
4. coalescing of sheets of hematite flakes to eventually produce an opaque replacement of original grain.

Fresh Biotite



Altered Biotite

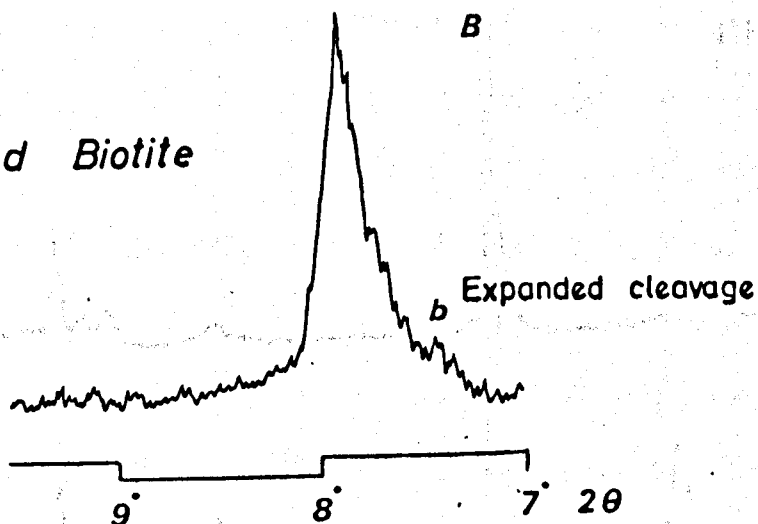


Figure 6.2 Portions of X-Ray Diffractograms of selected fresh and altered Biotite showing expansion of the 001 cleavage with hematite development.

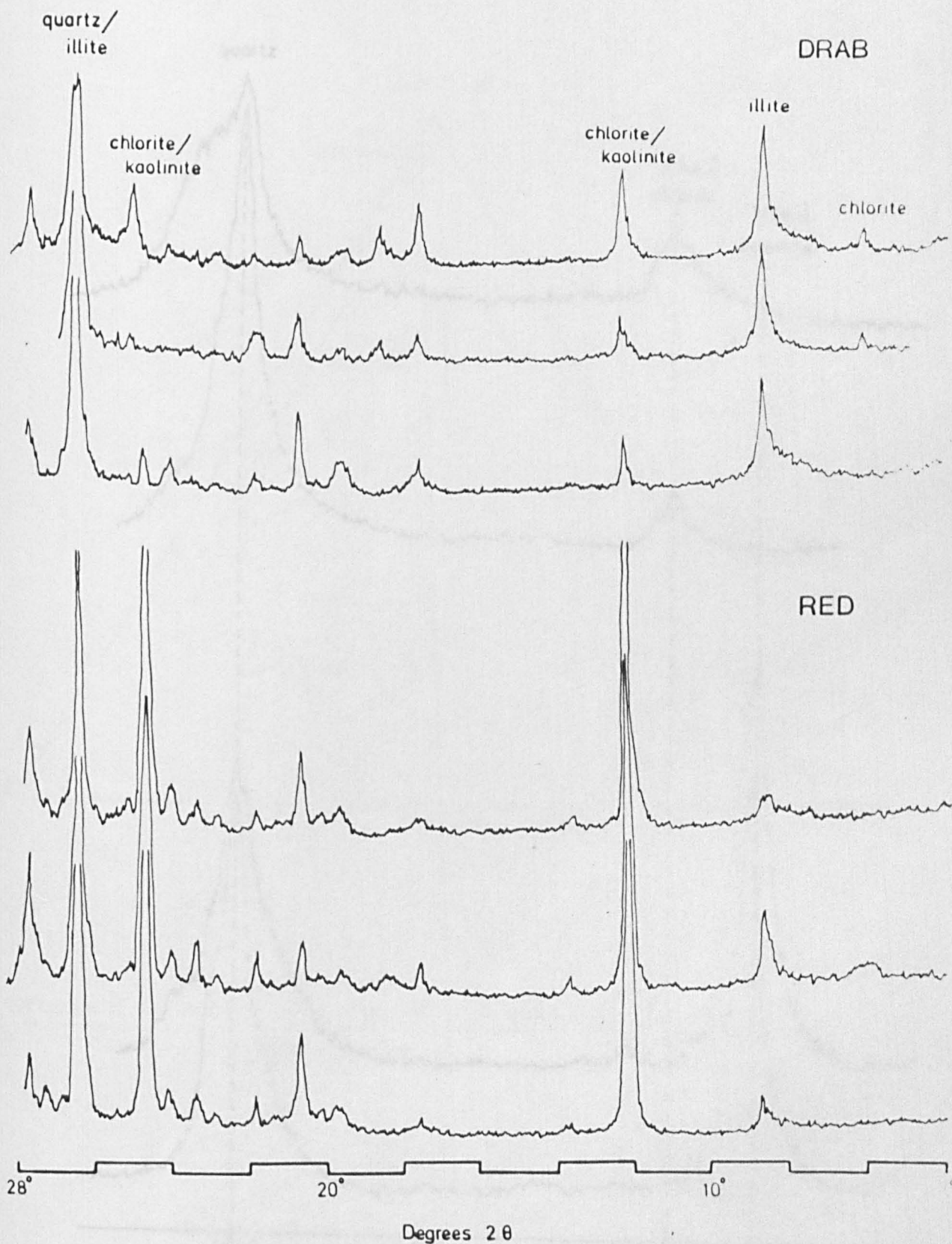


Figure 6.3 Examples of X-Ray Diffractograms of clay fractions from Red and Drab sediments.

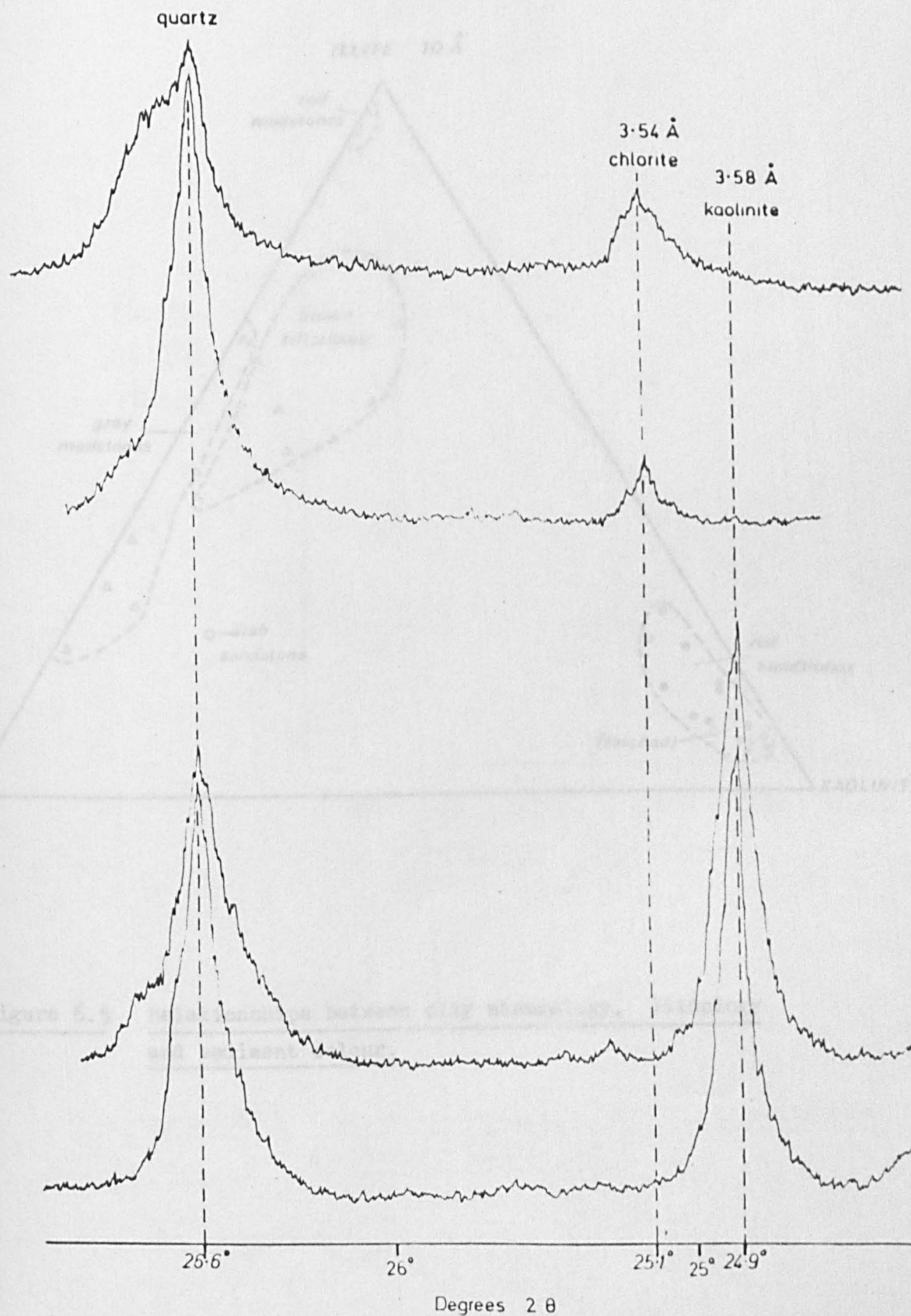


Figure 6.4 Portions of X-Ray Diffractograms of clay fractions of Red and Drab sediments showing separation of Chlorite and Kaolinite peaks by 'slow scan' method.

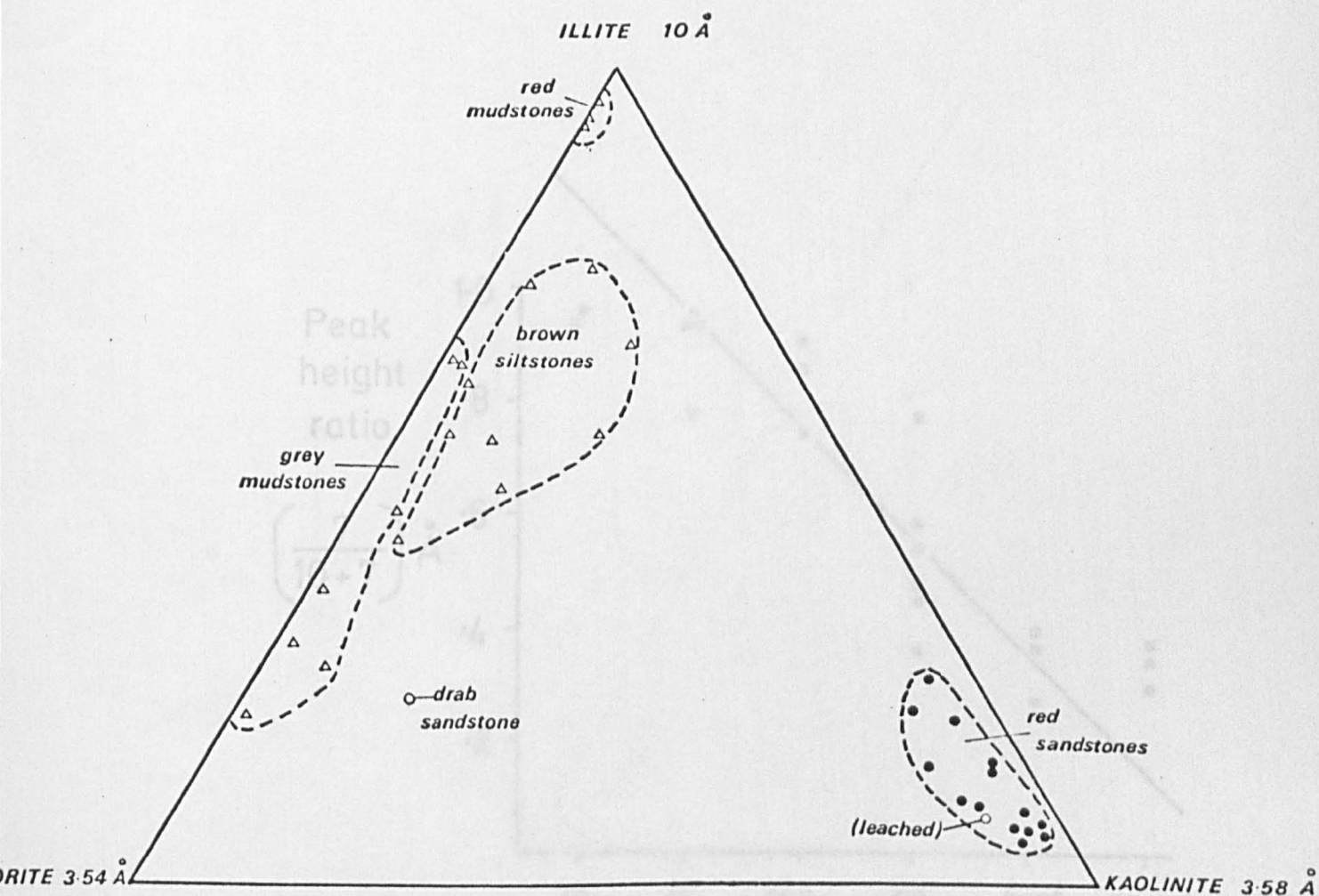


Figure 6.5 Relationships between clay mineralogy, lithology and sediment colour.

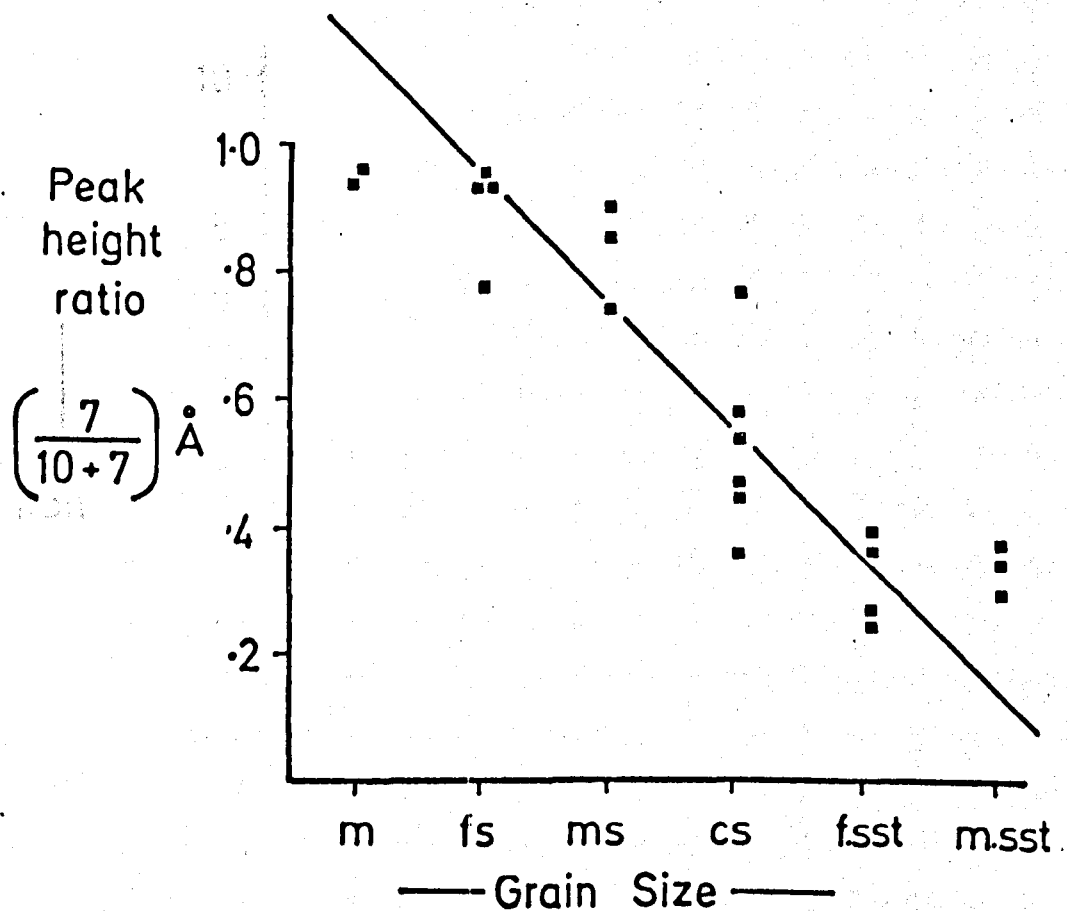


Figure 6.6

Grain-size correlation with the chlorite-plus kaolinite / illite ratio.

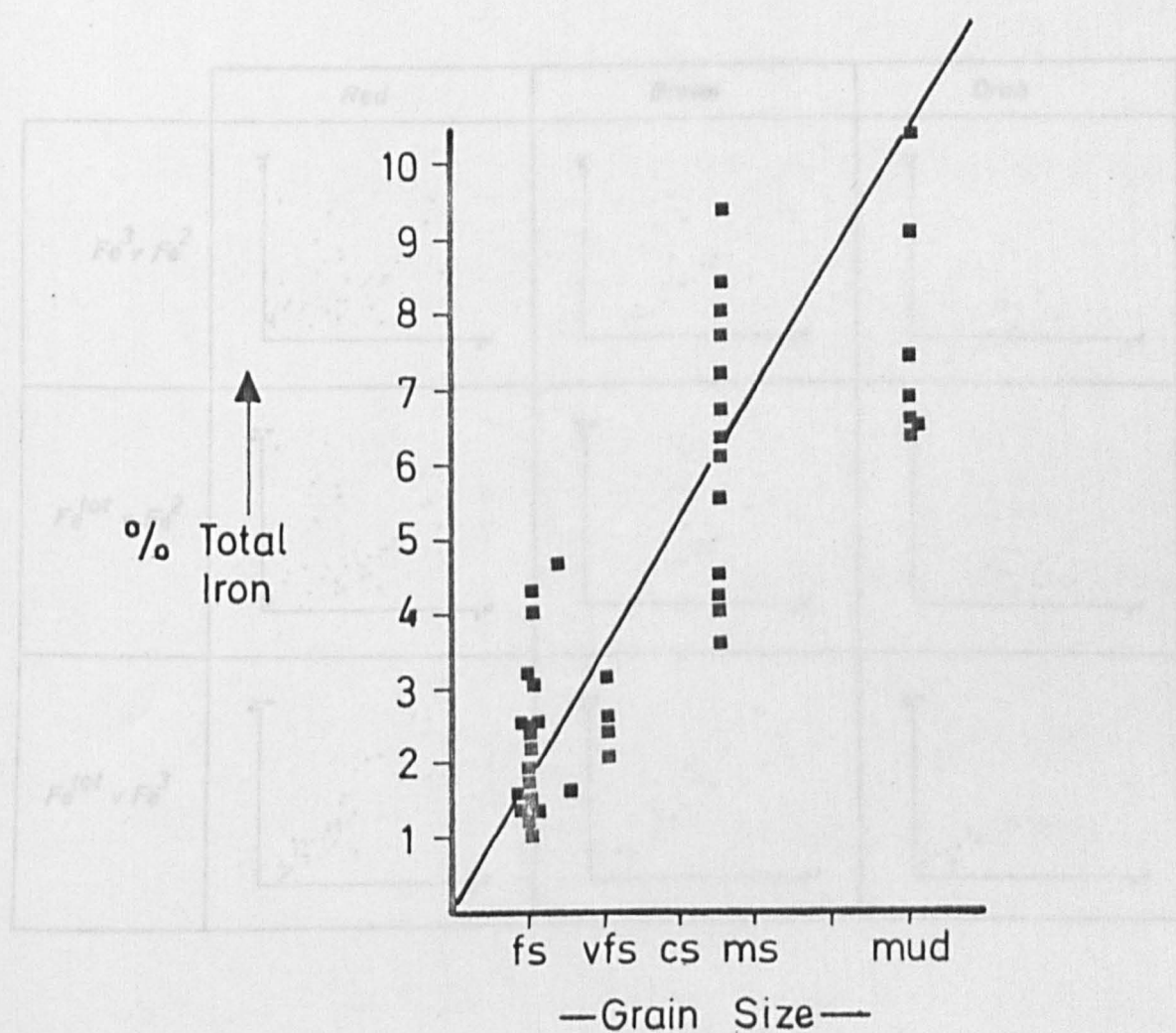


Figure 6.8

Summary of data for the relationship between Ferric, Ferrous, and Total Iron and Grain Size in sediments.

Figure 6.7 Influence of grain size on total iron content of sediment.

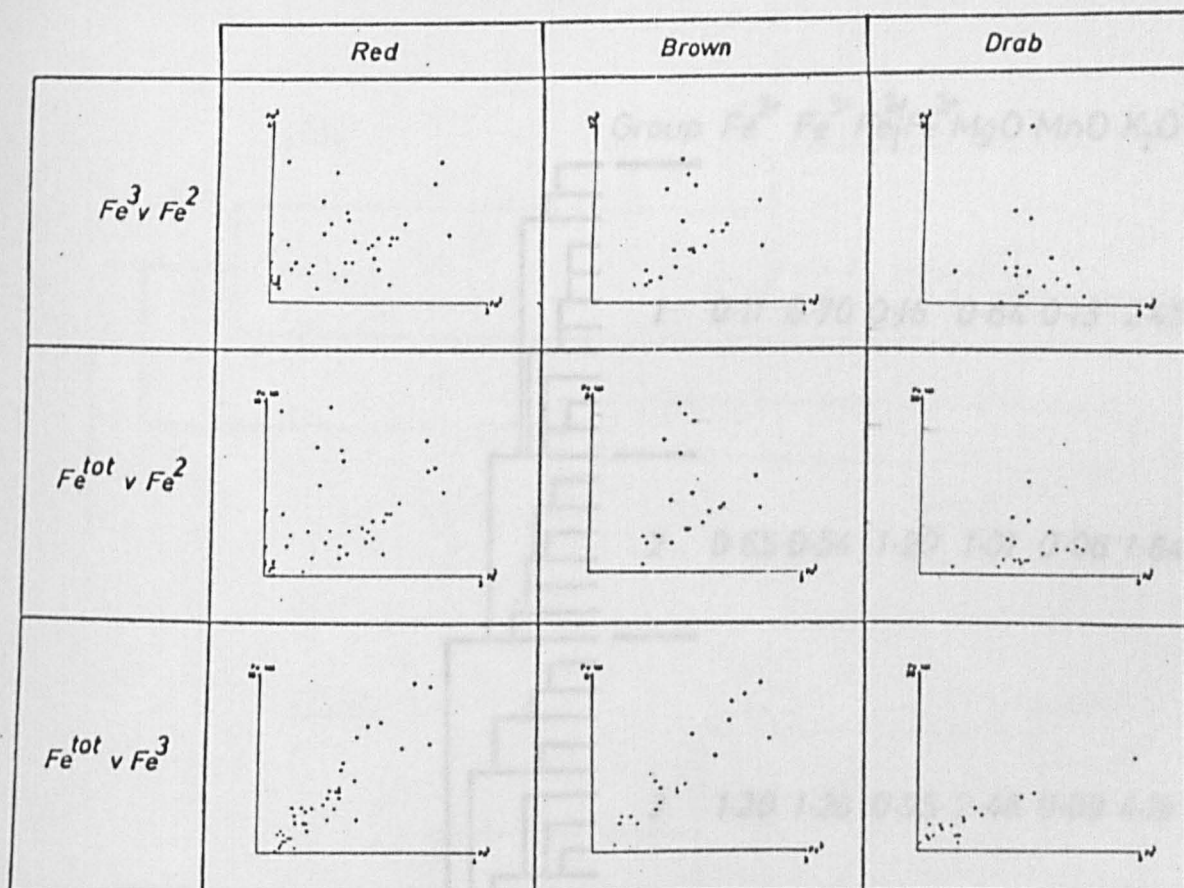


Figure 6.8 Summary of chemical analysis showing relationships between Ferric, Ferrous and Total Iron in Red, Brown and Drab sediments.

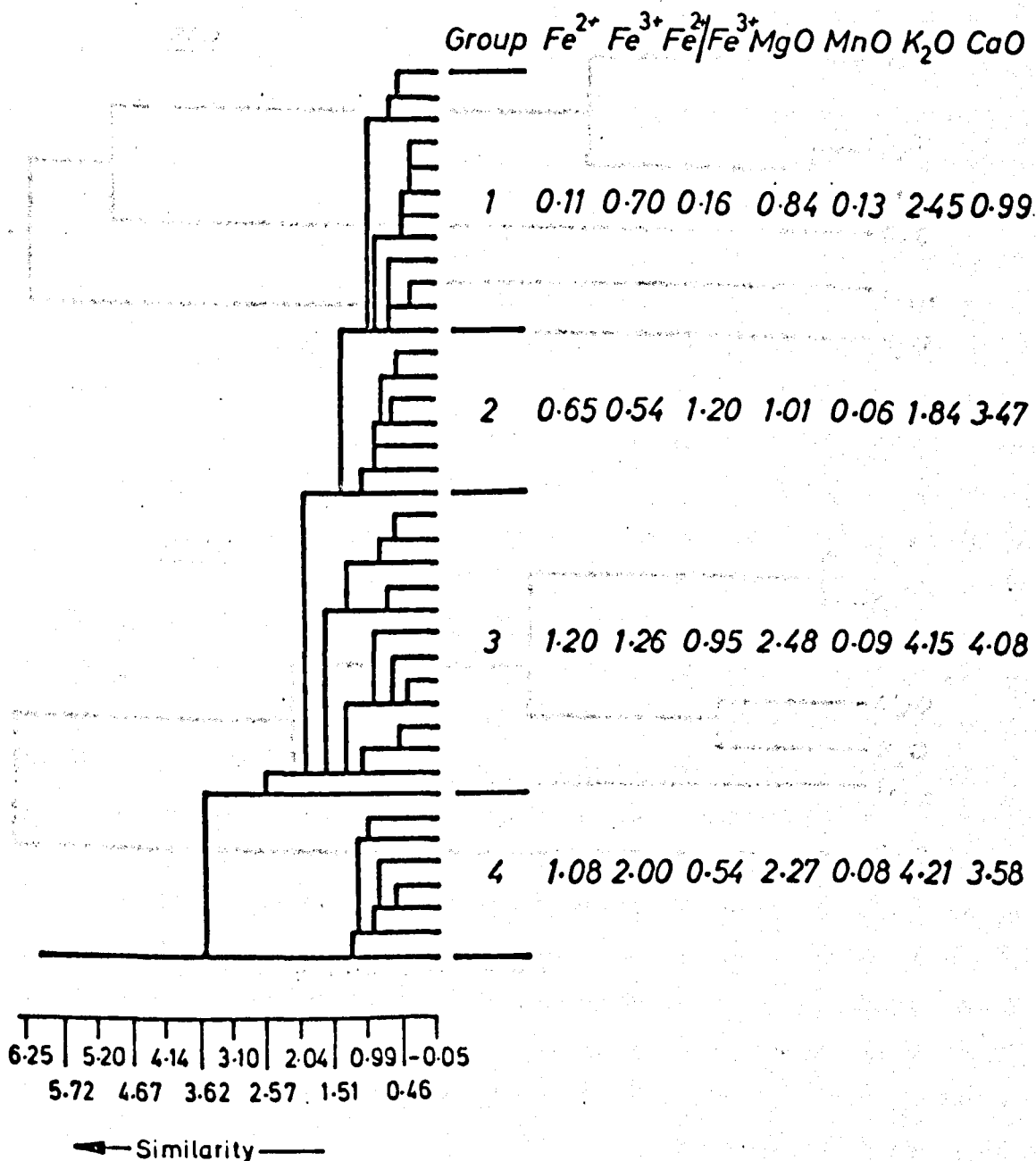


Figure 6.9 Q-Mode dendrogram showing the relationship between chemical analysis of individual sediments in terms of major elements.

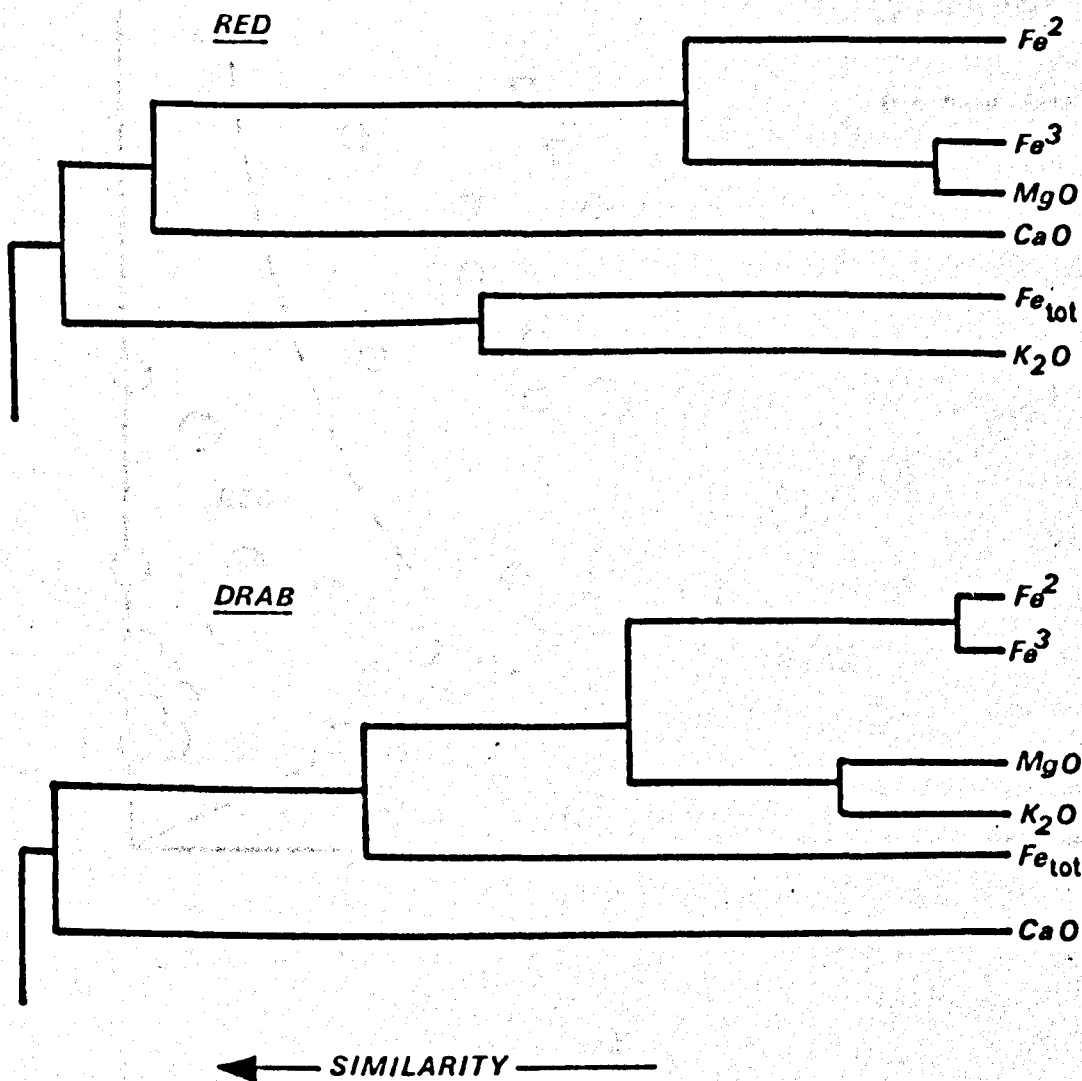


Figure 6.10

R-Mode dendrogram showing the relationship between major elements analysed in both red and drab sediments.

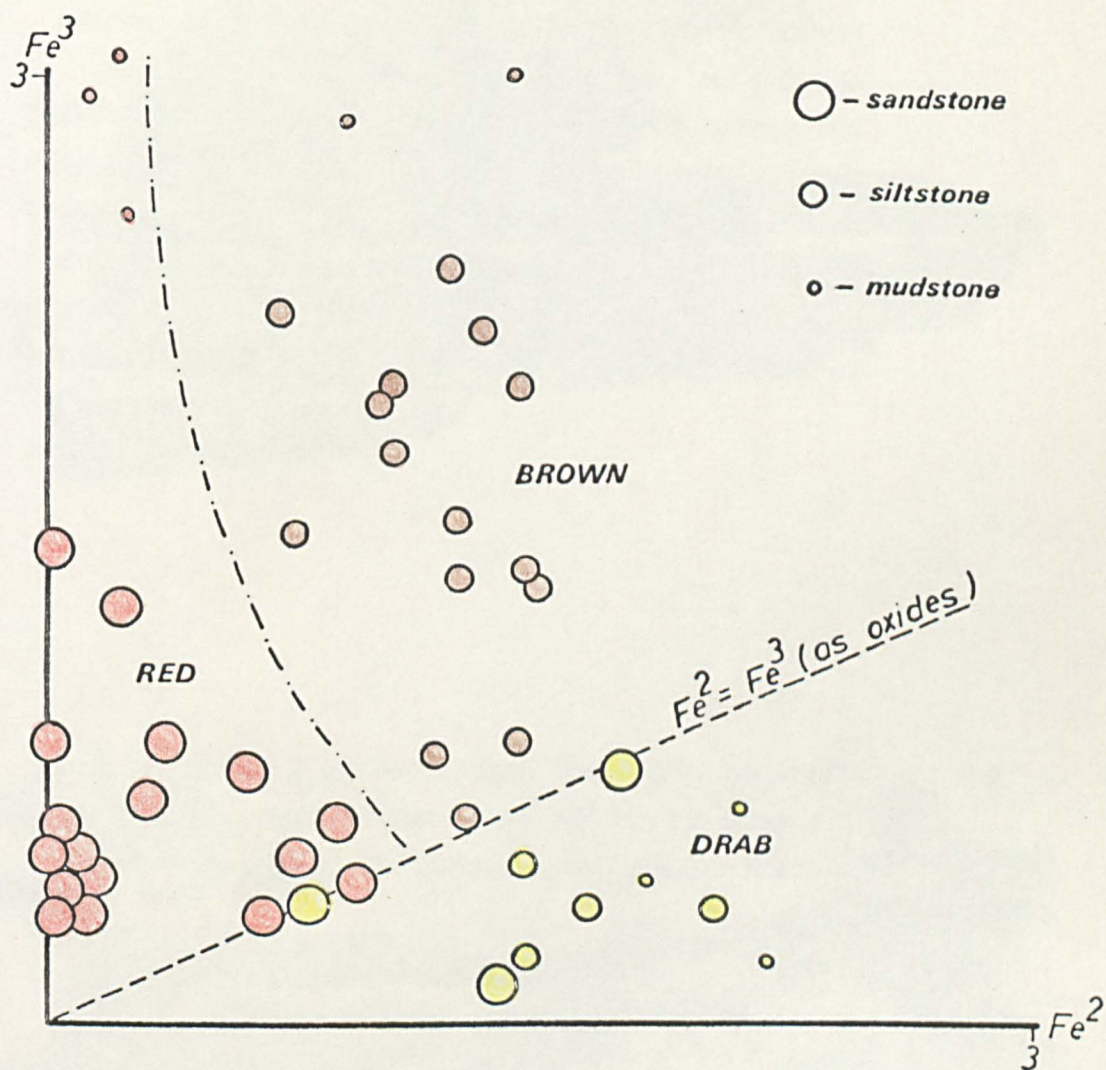
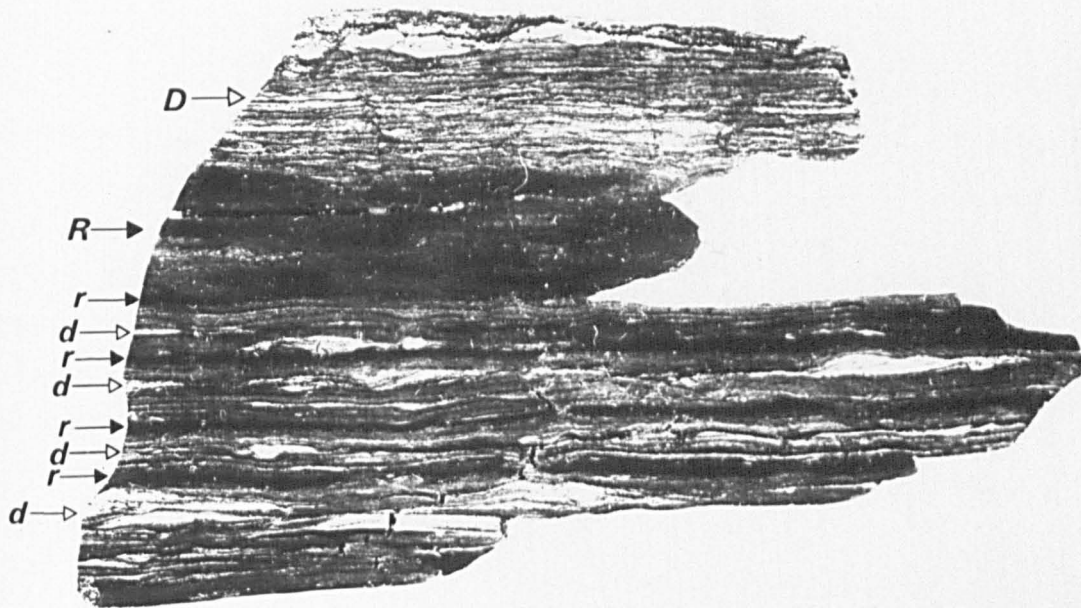


Figure 6.11

Relationship between Ferric and Ferrous iron,
grain size, and colour in the sediments analysed.

- A. Laminated mudstone from the West Harbour Formation showing the influence of grain size upon colour. The graded units show that the coarser silt/v.f.sand portion remains drab, whilst the fine upper portion (mud) is intensely hematized, producing a distinct red (r) - drab (d) alternation. Thicker regions of coarse or fine sediment maintain this colour difference in broad red (R) or drab (D) zones. (scale: natural size).
- B. Mudstone intraclast transected by a reduction spot. The area within the spot remains drab, whilst the area outside is intensely hematized. (field width 1mm)

a



b

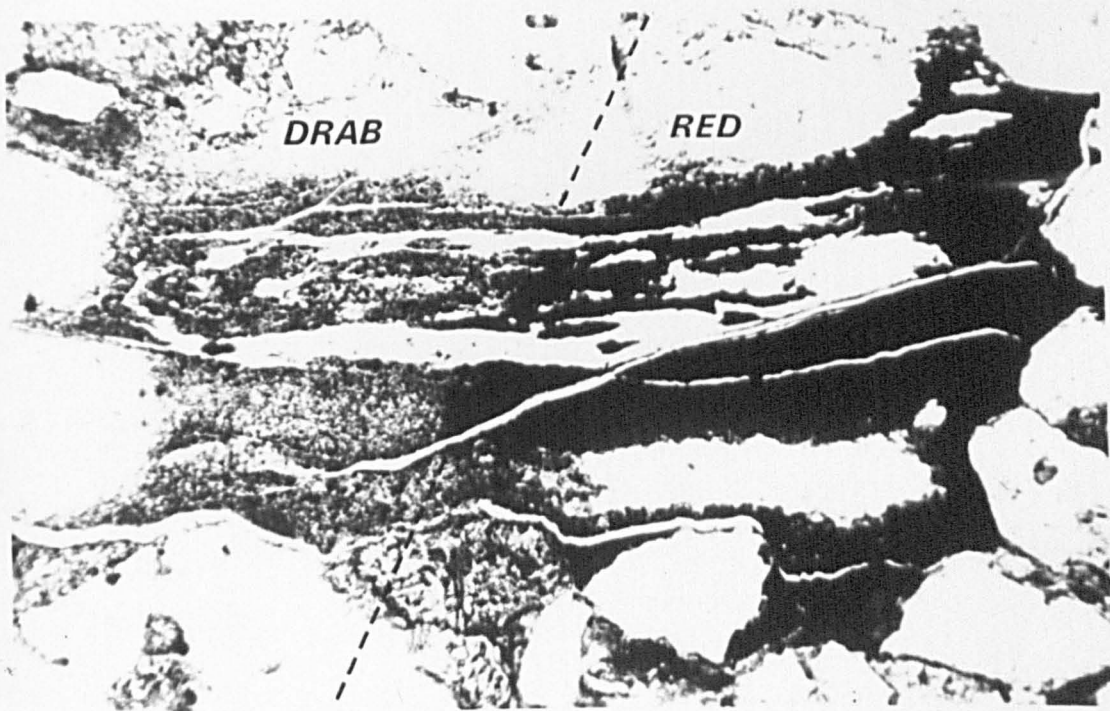


Plate 6.2

Polished surface of a ripple laminated sandstone from the Quarryhill Sandstone Formation near Rhynie. Biotite mica is abundant in the lee of the ripple structure, appearing as a broad diagonal zone. Hematisation of detrital mica has occurred, but significantly, the in-situ degradation of such micas has resulted in the very local remobilisation of hematite.

The remobilised hematite is now concentrated in small spots around large mica flakes in the lee of the ripple. (scale: width of field 15cm)



Plate 6.3 General form of hematite pigment within the sediments.

- A. Photomicrograph of hematite on a grain surface (red pigment).
Note the general consistency of size, and in particular
the pseudohexagonal form of some of the flakes.
(scale: field width 110 μ m).
- B. Highly magnified view (photomicrograph) of a biotite
flake from a red sandstone showing the intercleavage
development of thin sheet like flakes of hematite (arrowed).
(scale: field width 110 μ m).

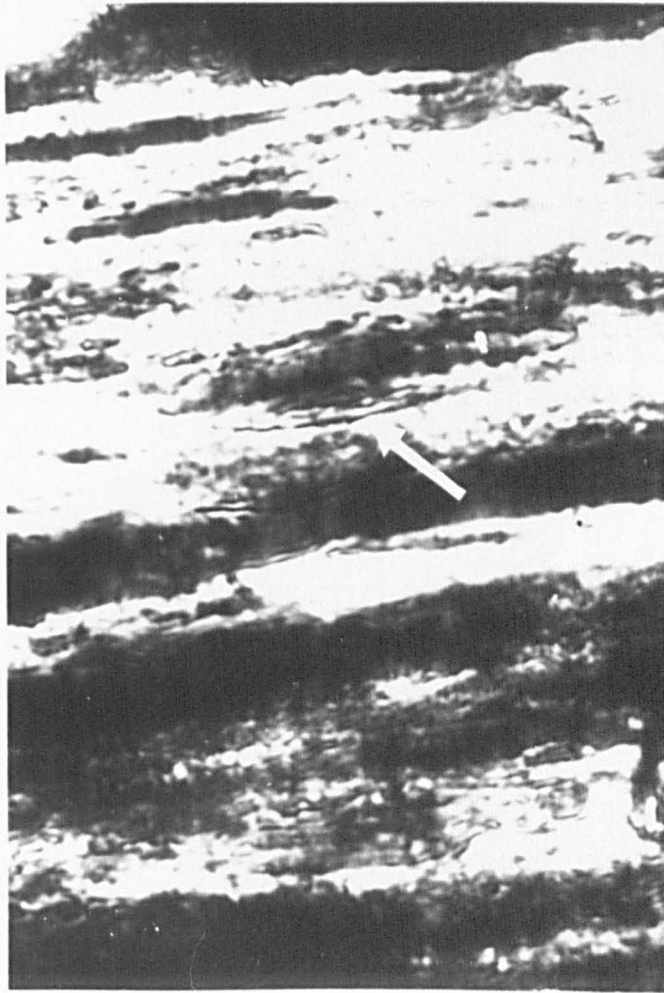
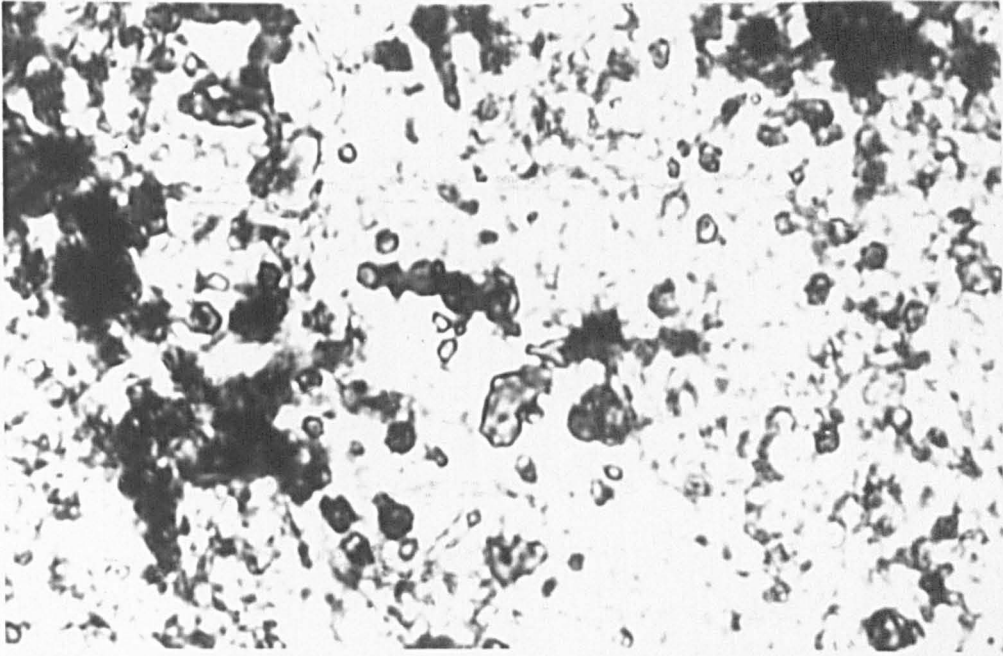
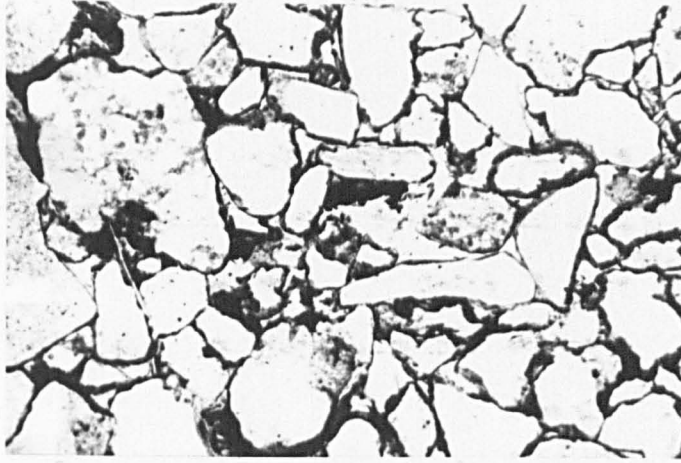
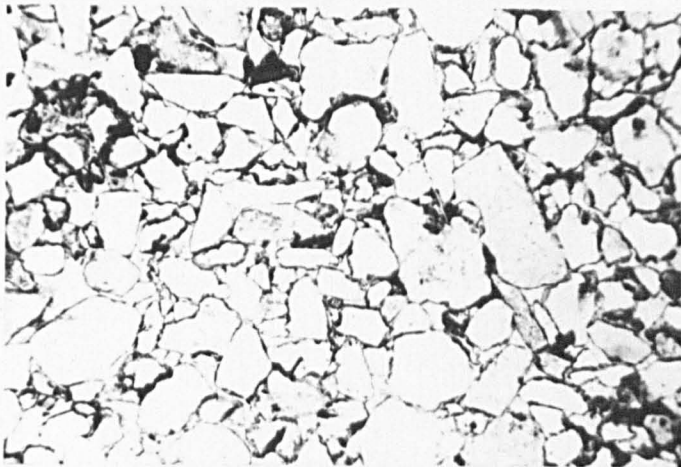


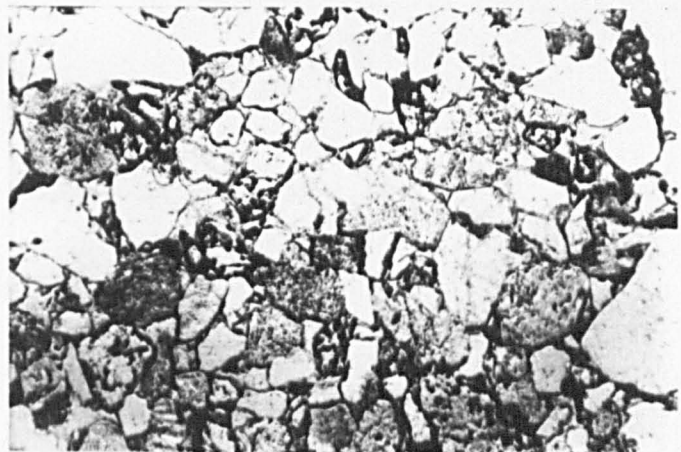
Plate 6.4 A series of photomicrographs showing the general form of hematite pigmentation as grain coatings in red sandstone (plates a, b, and c) compared with the absence of pigment in a drab sandstone (plate d).
(scale: field width in all cases 1 mm).



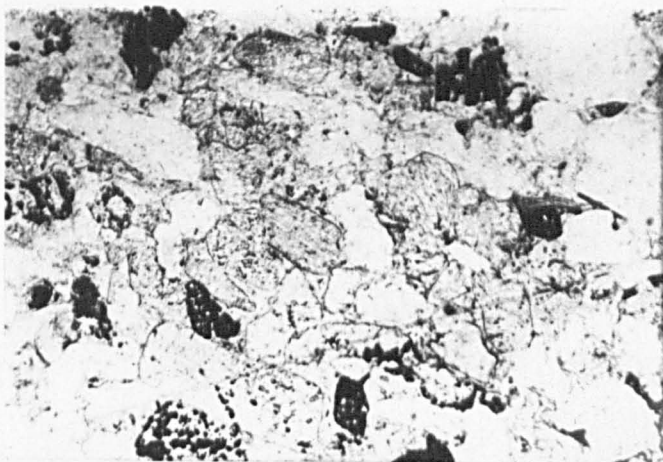
a



b



c

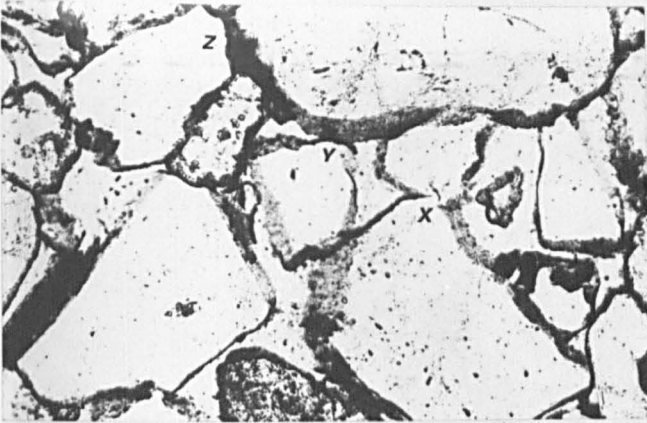


d

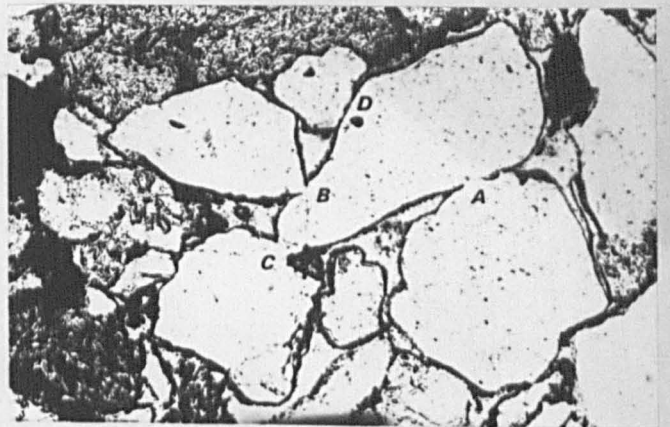
Plate 6.5 Photomicrographs demonstrating the form of the
hematite grain pigment.

- A. Thick pellicle of hematite which may be absent from grain contacts (x), present at grain contacts (y), or very thick in areas of grain contact (z). (scale: field width 0.75mm)
- B. Thin, dense pellicle of hematite showing a lack of pigment on most contacts (a, b, c), but present on others (d). (scale: field width 0.75 mm)
- C. Further view of hematite coating to grains, this time all contacts show the presence of pigment. (scale 0.75 mm)
- D. Enlargement of grain contact showing finely divided hematite pigment on grain contacts. (scale: field width 0.5mm)
- E. Enlargement of grain contact showing absence of hematite pigment in a region where quartz overgrowth has occurred. (scale: field width 0.75mm)
- F. Enlargement of grain contact showing lack of pigment in the case of a simple grain contact with no overgrowth. (scale: field width 0.25 mm)

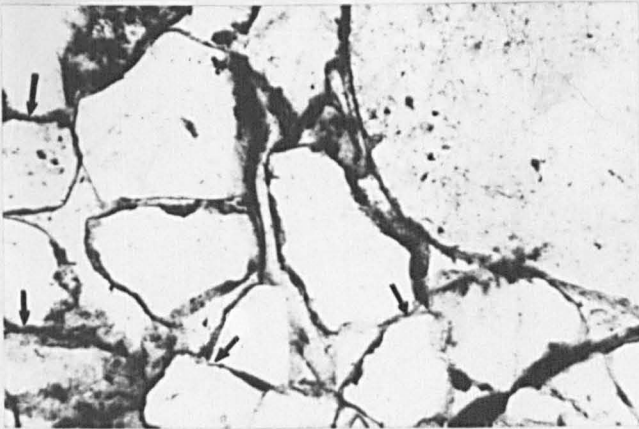
a



b



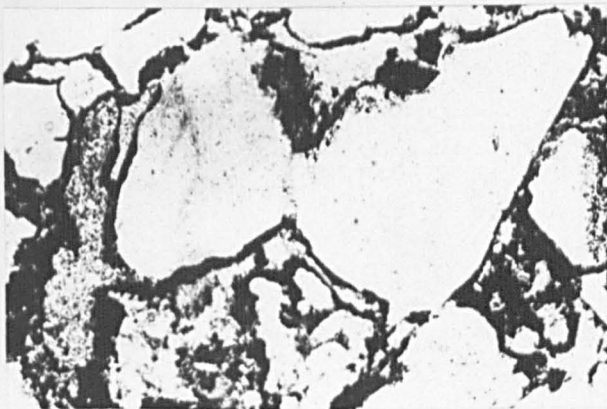
c



d



e



f

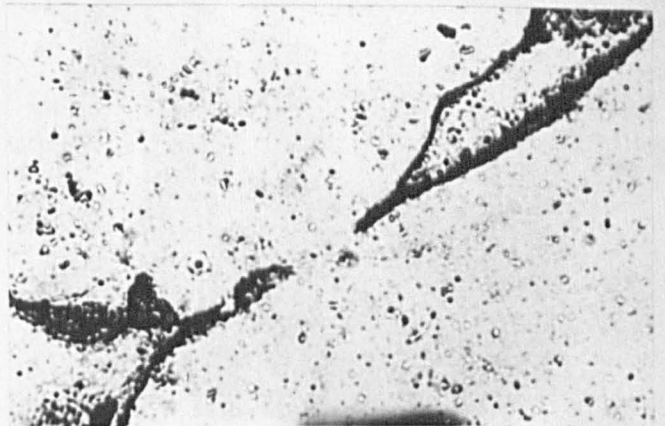


Plate 6.6 Other textural sites for hematite.

- A. Irregular shaped hematite in fine sandstone,
but still showing distinct boundaries.
(scale: field width .45mm)

- B. Irregular shaped hematite within a red sandstone
showing indistinct boundaries, and enclosing
small detrital silt grains. Possibly a hematized
intraclast. (scale: field width 0.5 mm)

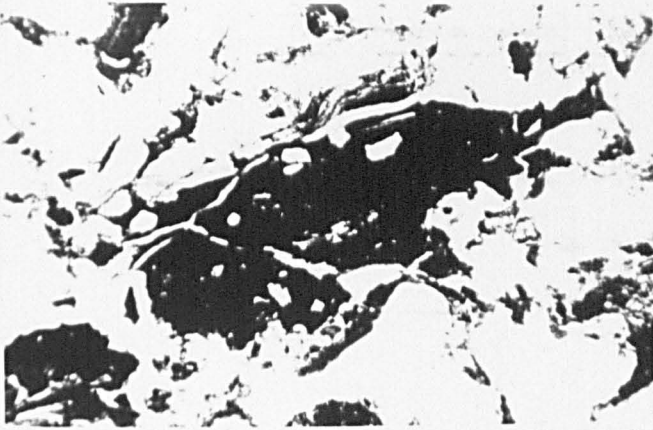
- C. Dense area of hematite showing signs of remobilisation.
Hematite is penetrating into cracks, and between grain
contacts (b, c, d). (scale: field width 0.5 mm)

- D. Further example as above. Such instances may provide
evidence of remobilisation of detrital hematite grains.
(scale: field width 0.5mm)

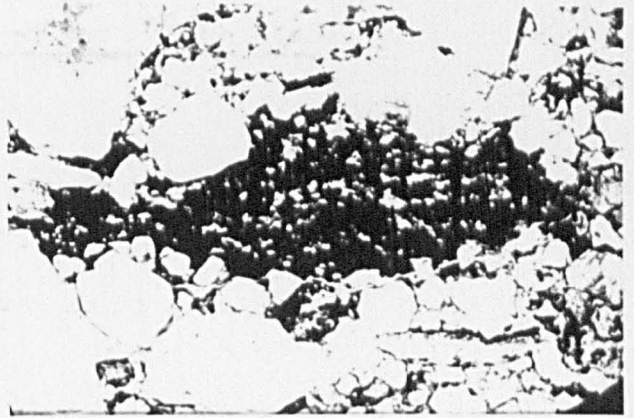
- E. Hematite grain (detrital) sandwiched between grain
contacts, and having suffered subsequent deformation
and remobilisation. (scale: field width 0.5 mm)

- F. Hematite pigment concentrated within an embayment
on a detrital quartz grain. (scale: field width 0.5mm)

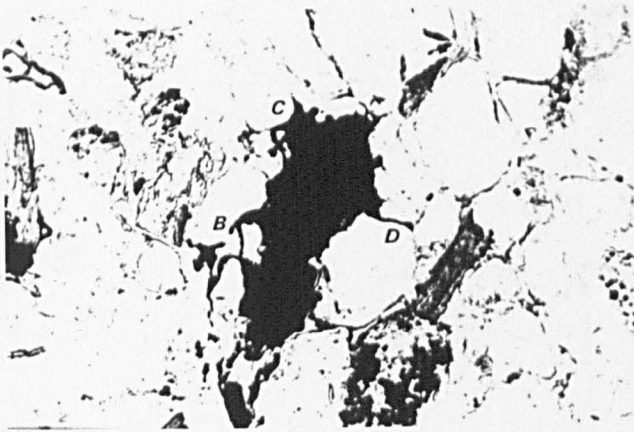
a



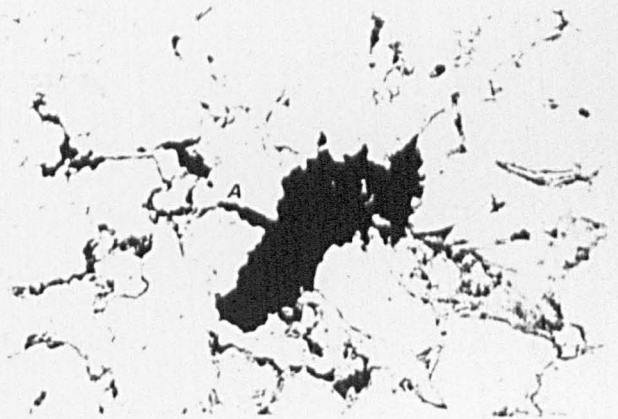
b



c



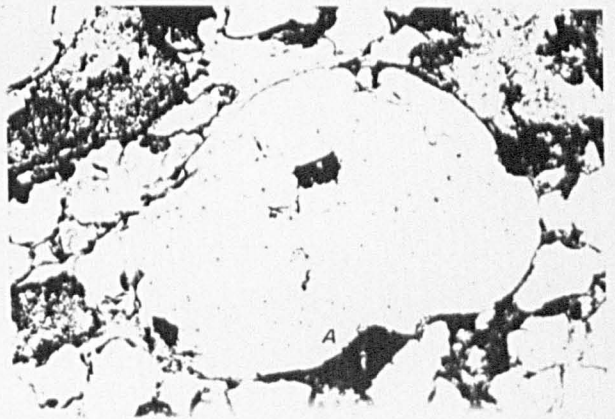
d



e



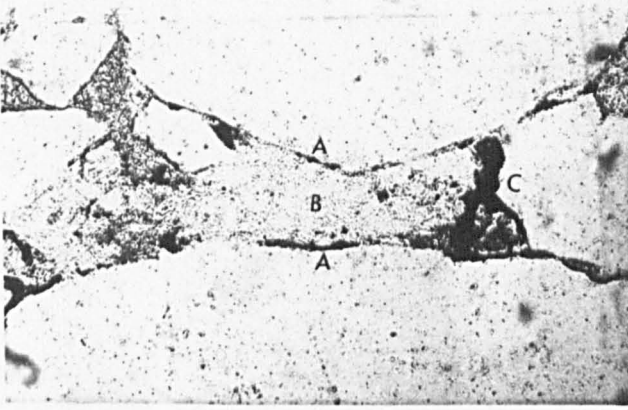
f



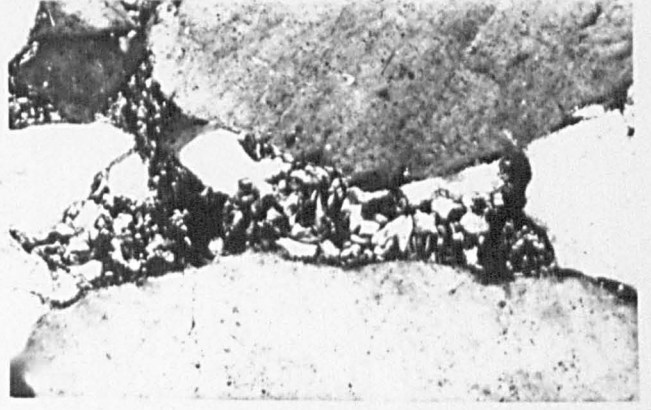
In the following series of photomicrographs, the same field is displayed on the right under crossed polars.

- A,B Quartz grains almost in contact, separated by a small development of authigenic kaolinite (b). The kaolinite is coated with a relatively thick layer of hematite before a pore filling phase of calcite (c). (scale: field width 0.15 mm)
- C,D An extensive pore filling of kaolinite (b), this time clearly postdating a thick development of grain coating hematite. (scale: field width 0.5 mm)
- E,F Plagioclase feldspar showing a coating of hematite pigment, plus smaller amounts of hematite on cleavage plains. Pigmentation was then followed by a slight feldspar overgrowth, which appears unpigmented. (field width: 0.5 mm)

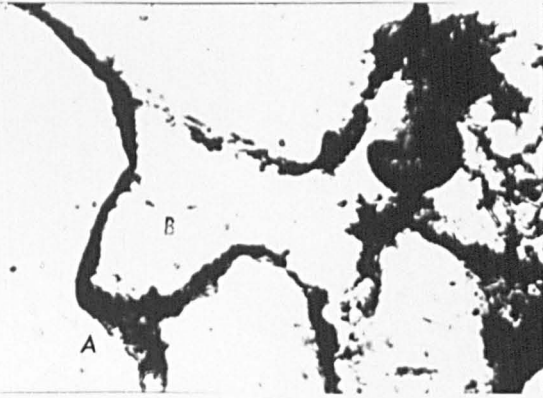
a



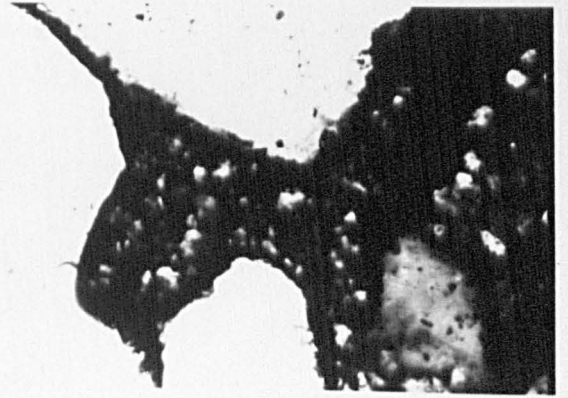
b



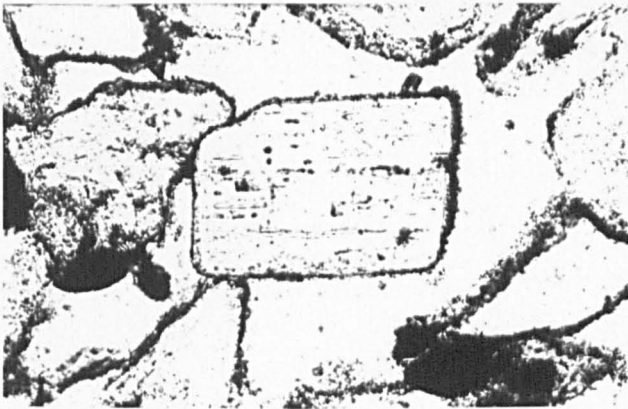
c



d



e



f

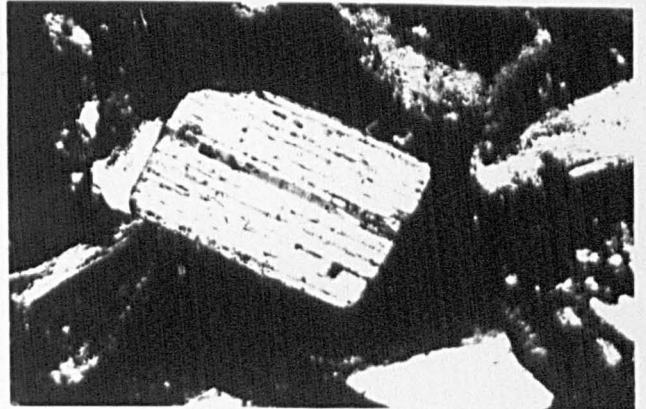


Plate 6.8 Relationship of hematite development to other mineral developments.

- A. Detrital quartz grains with irregular overgrowths.
Note that the detrital grains are pigmented prior to the overgrowth. Extensive pore filling by hematite followed. (scale: field width 0.75mm)

- B. Extreme cavity lining by hematite in a red sandstone.
(scale:field width 0.75mm)

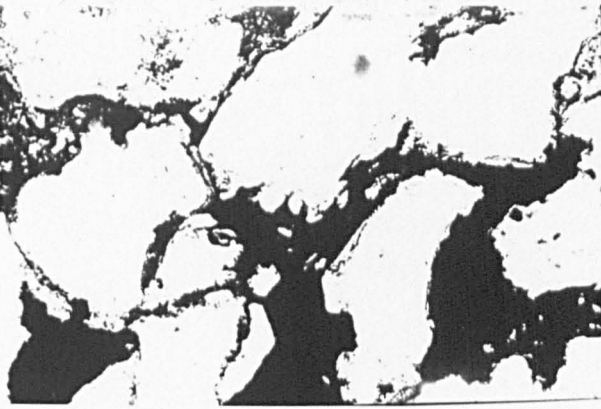
- C. A small overgrowth on a detrital quartz grain with no apparent initial hematite pigment. Followed by extensive hematite in a pore filling phase.
(scale:field width 0.5 mm)

- D. Intergrowth of hematite and kaolinite.
(scale: field width 0.5mm)

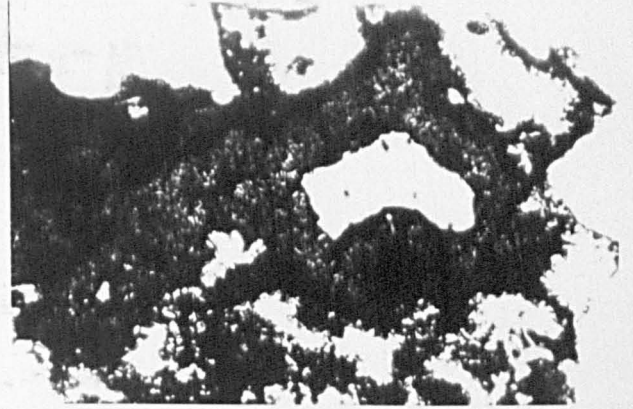
- E. Enlarged view of euhedral quartz overgrowth.
(scale: field width 0.1 mm)

- F. Enlarged view of kaolinite intergrowth with hematite.
(scale:field width 0.05mm)

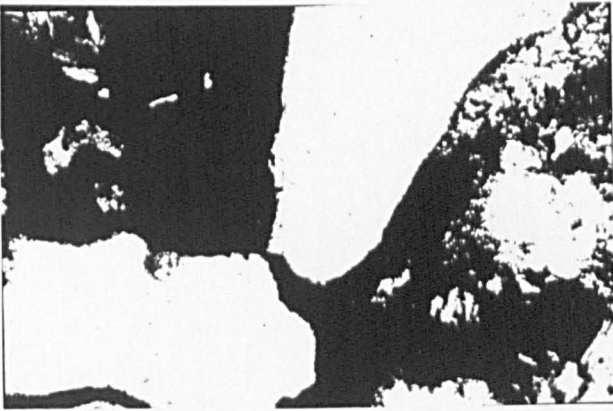
a



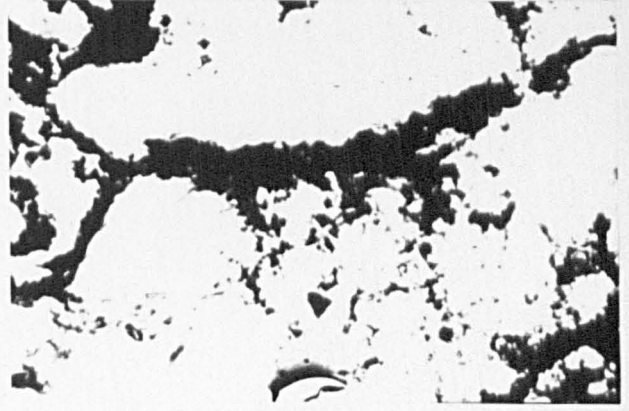
b



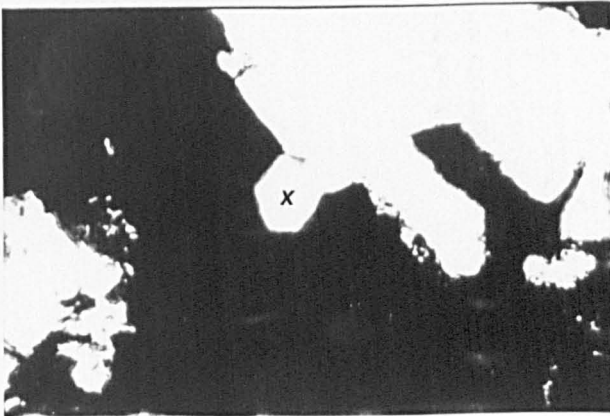
c



d



e



f

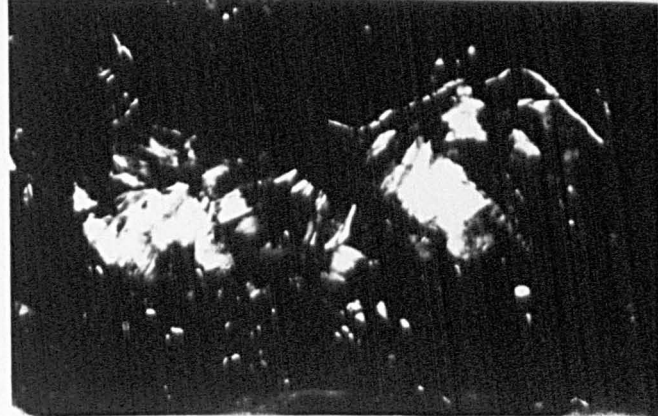


Plate 6.9 Scanning electron micrographs of mineral developments
within red sandstones.

- A. Detrital quartz grain (Q) showing an adjacent pore filling of calcite (C). (scale: field width 50 μ m)

- B. Quartz grains showing an intergrain development of coarse grained kaolinite. Note the 'book' form common in the variety Dickite. (scale: field width 50 μ m)

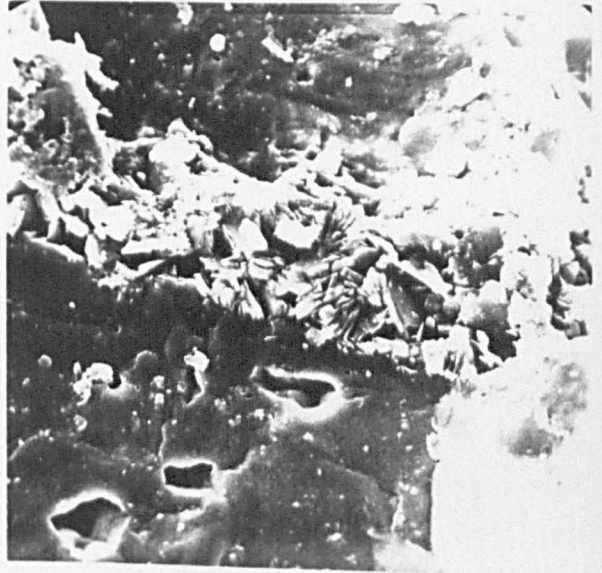
- C. Quartz grain (Y), with coating of iron oxide possibly goethite, and showing a colloform texture.
(scale: field width 50 μ m)

- D. Authigenic feldspar growing within a biotite flake.
(scale: field width 25 μ m)

a



b



c



d

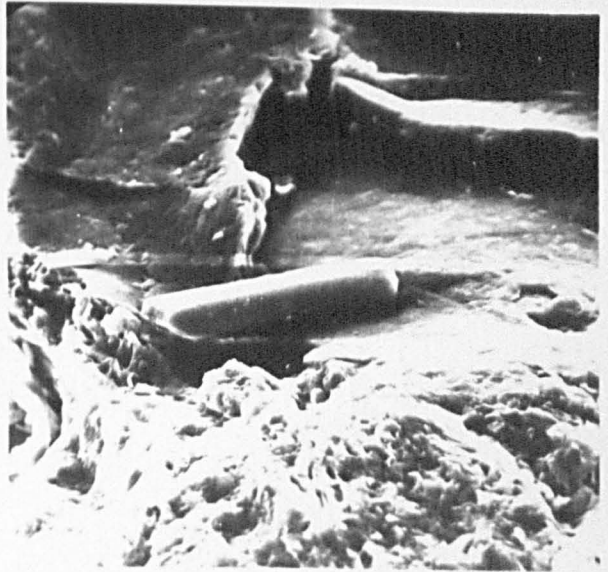
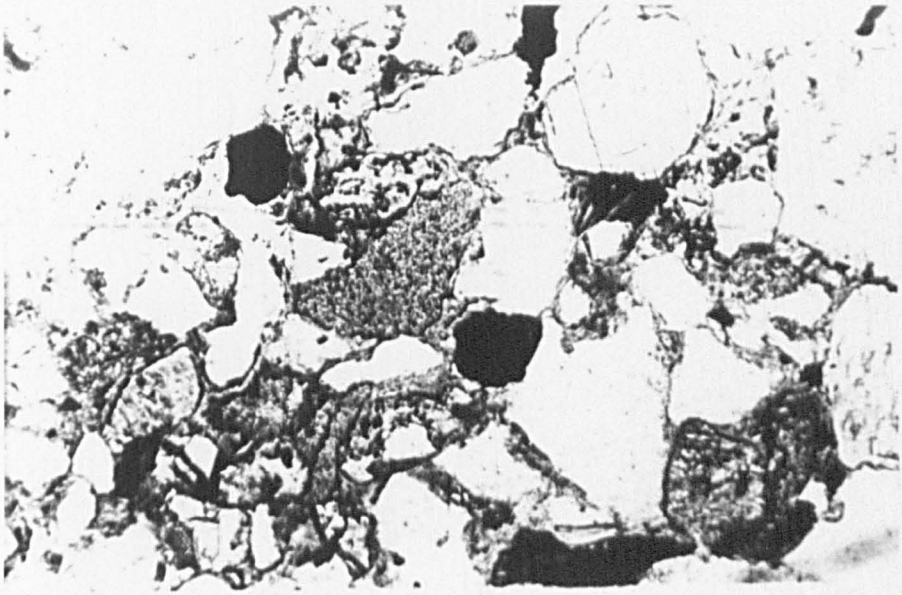


Plate 6.10 A selection of detrital opaque oxides found
within red sandstones.

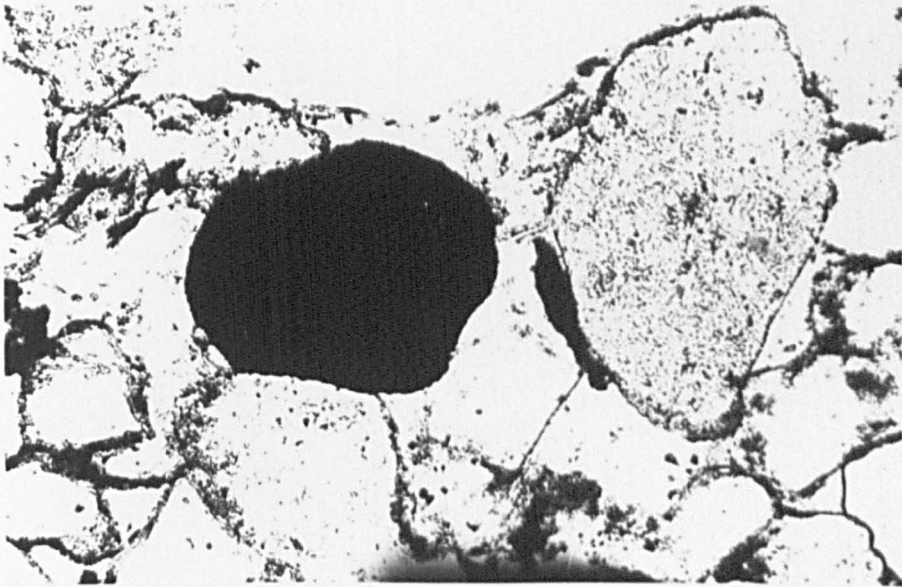
- A. Irregularly shaped detrital opaque oxide grains.
(scale: field width 0.5 mm)

- B. Detrital opaque oxide showing very well-rounded
form. (scale: field width 0.3 mm)

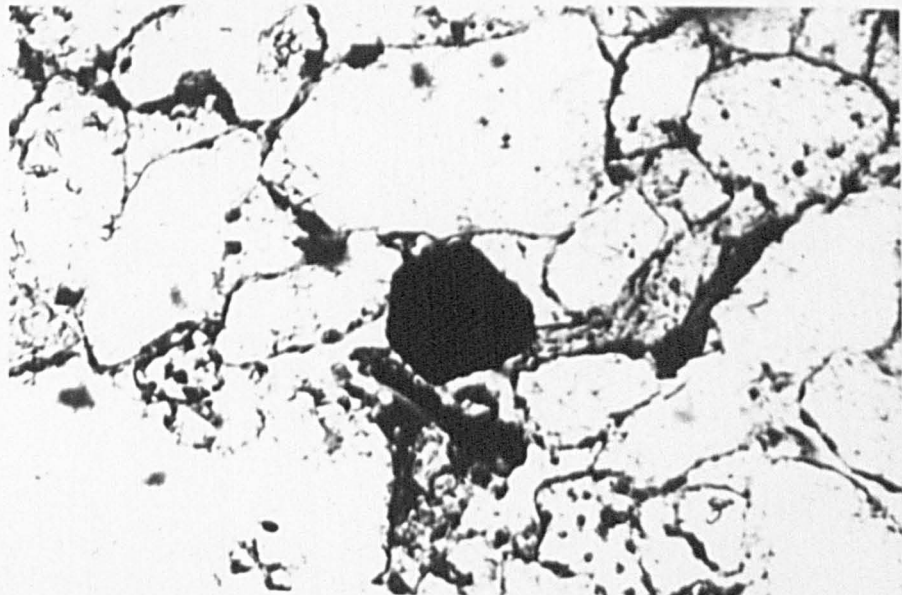
- C. Detrital opaque oxide grain showing a pseudo-
hexagonal form, suggesting minimal transport.
(scale: field width 0.3 mm)



a



b



c

Plate 6.11 Photomicrographs of polished blocks showing the nature of the detrital hematite grains, and form of the hematite within a hematized biotite.

- A. Detrital hematite grain showing intense corrosion pits and channels, plus boundary corrosion leaving a grain shape unlikely to have survived transport. (scale: field width 0.15mm)
- B. Polished section through a hematized biotite mica showing high reflecting hematite occupying a cleavage site. (scale: field width 0.15mm)
- C,D Detrital hematite grain showing abundant corrosion pits, and under crossed polars (plate D) a faint martitisation texture is apparent. This implies that the grain is a hematized magnetite grain. (scale: field width 0.15 mm)
- E,F Further example of a detrital hematite grain showing distinct corrosion channels parallel to the martitisation texture apparent under crossed polars (plate F) . (scale: field width 0.15 mm)

In the above photomicrographs, the grains shown were isolated using heavy liquid techniques, mounted in a methyl-methacrylate resin, and polished. The photographs were taken using 'Antiflex' x16 oil immersion objectives.

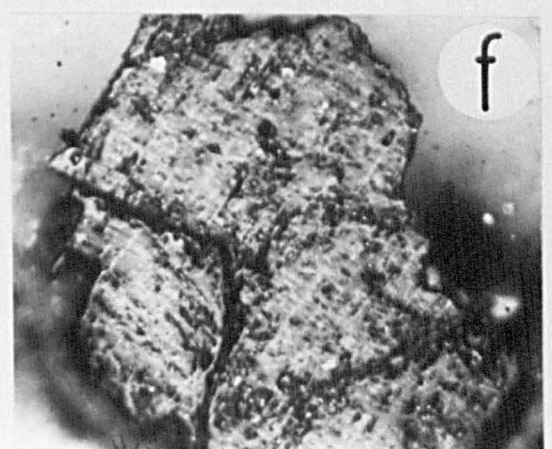
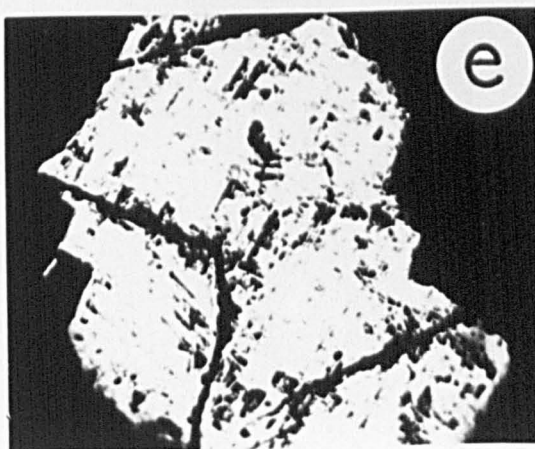
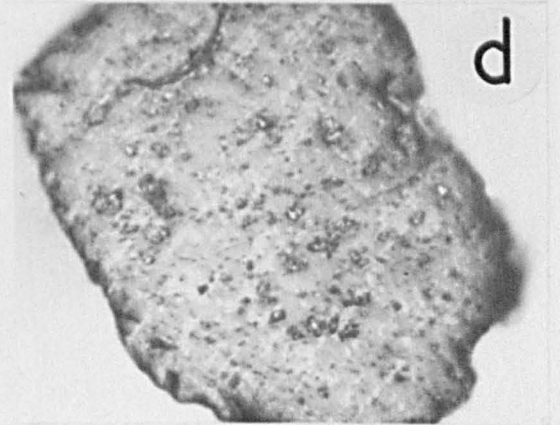
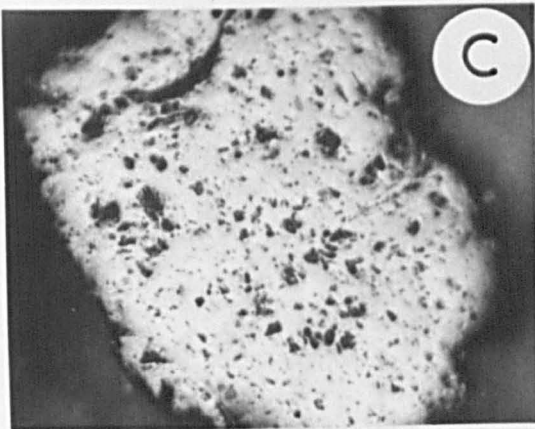
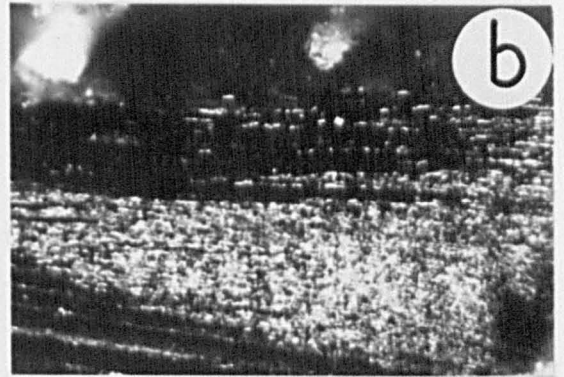
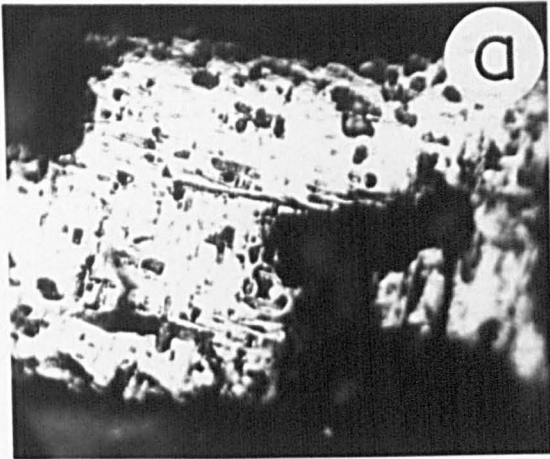


Plate 6.12 Series of photomicrographs showing the nature and location of hematite within biotites in red sandstones.

- A. General view of the form of the fine particulate hematite.
- B. Thin flakes of hematite occurring within intercleavage positions in a biotite flake.
- C. Early stage of hematisation of a detrital biotite.
Note slight hematisation of cleavages, most pronounced in areas where compaction has buckled and opened the cleavage.
- D. More advanced stage of hematisation where intercleavage hematite is extensive and begins to coalesce into distinct sheets.
- E. Similar to above, but note extensive hematite development again within a 'buckled' cleavage site.
- F. Mature stage of biotite hematisation prior to complete pseudomorphing of flake. Hematite exists in thick sheets, no longer in single cleavage sites. Sheets have coalesced.

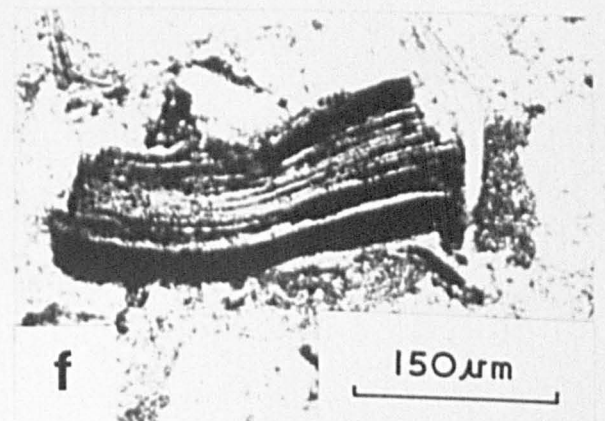
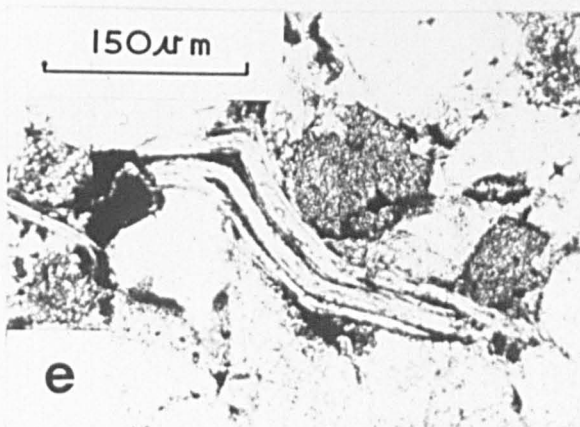
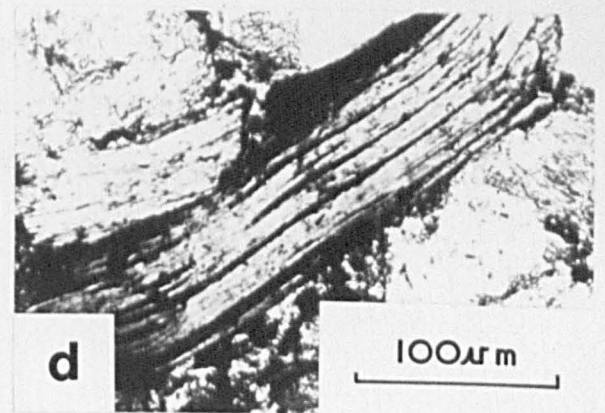
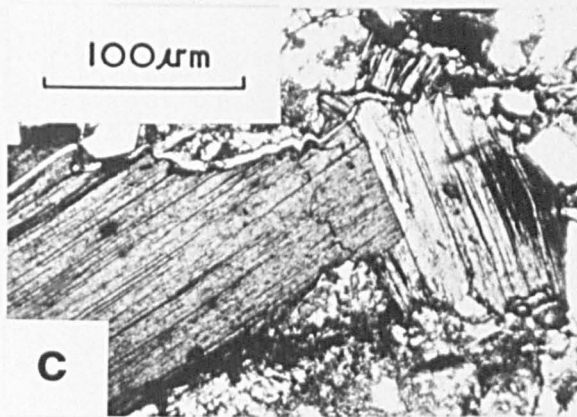
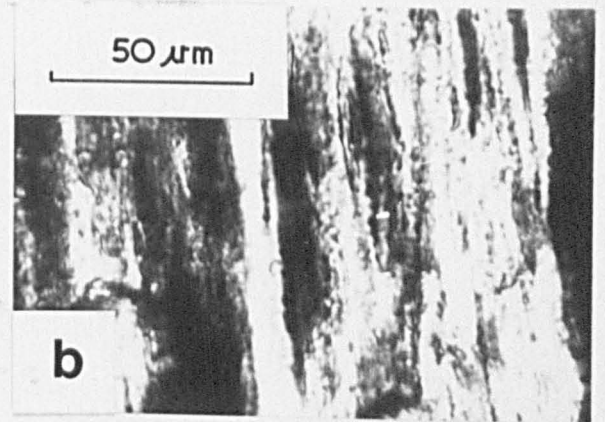
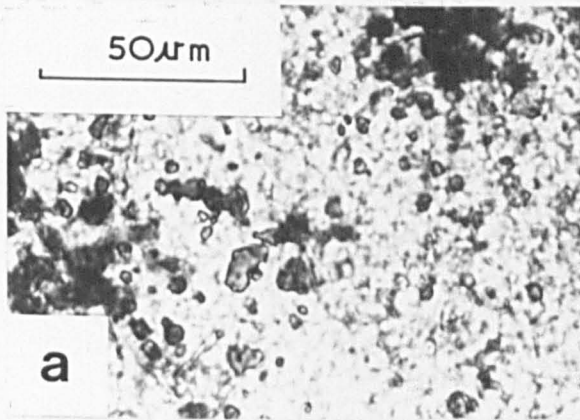


Plate 6.13 Scanning electron micrographs of hematite development
in biotite micas from red sandstones.

- A. Hand picked biotite flakes in various states of hematisation were selected from heavy mineral concentrates, and split to expose fresh cleavage surfaces.
- B. General view of hematite development on a cleavage surface. Note clustered, pseudo-hexagonal forms often stacked.
- C. Hematite development on a cleavage surface. Note range in size, and good pseudo-hexagonal form of larger flakes.
- D. Pseudo-hexagonal flake 'emerging' from the surface of a biotite cleavage flake.

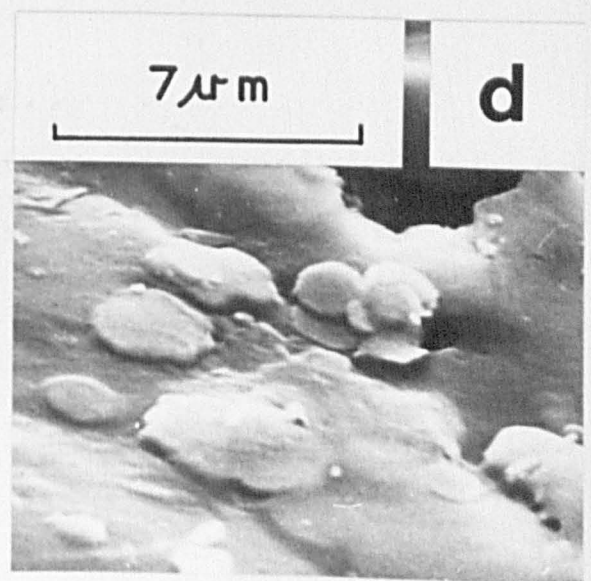
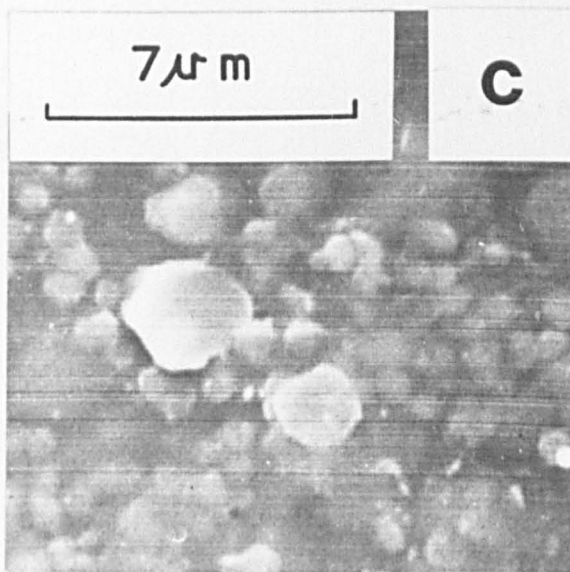
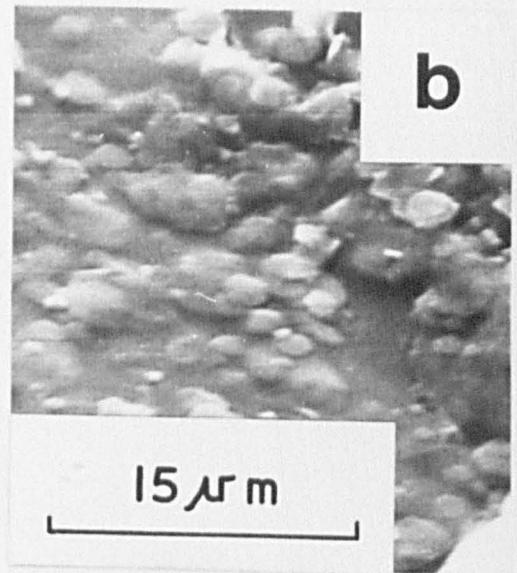
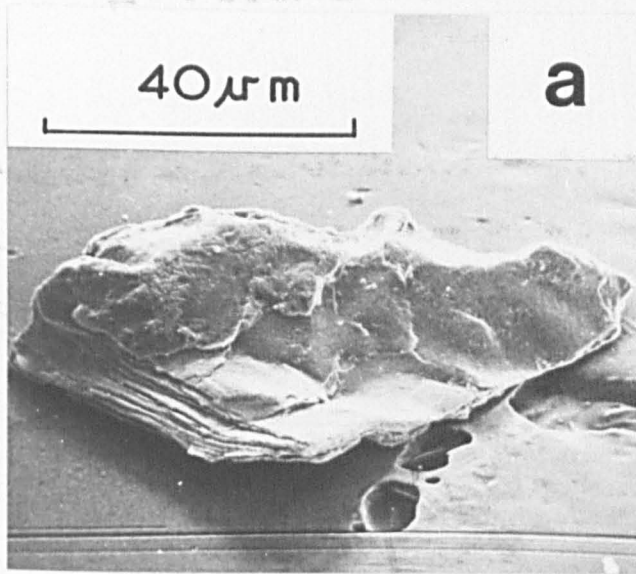


Plate 6.14 Summary of E.D.A.X. analysis of hematite development stages.

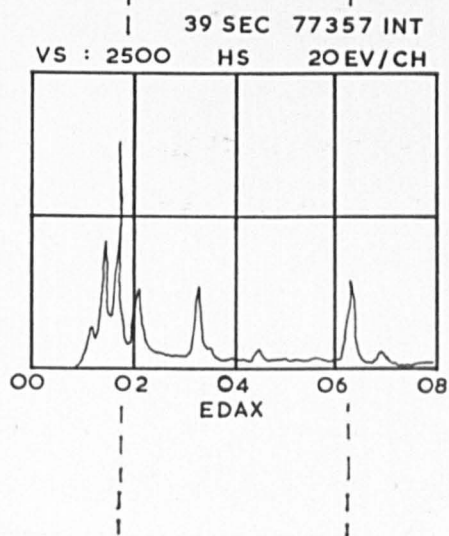
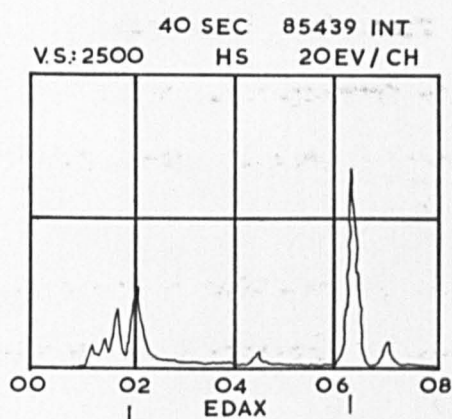
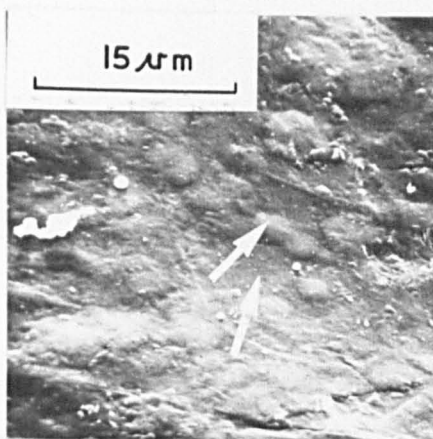
The adjacent series of electron micrographs and copies of EDAX traces demonstrate the concentration of Fe in preference to Mg, Al, and Si in regions where hematite is developing. Plate (a) illustrates a relatively early stage in hematite development, while (b) shows an advanced stage where flakes of hematite are beginning to separate.

Diagram (1) shows the relative concentration of the elements mentioned in areas of hematite flake development.

Diagram (2) compares this composition in background areas where no development is apparent.

Note that in the very early stage of hematite development the cleavage surface merely develops small 'dimples'.

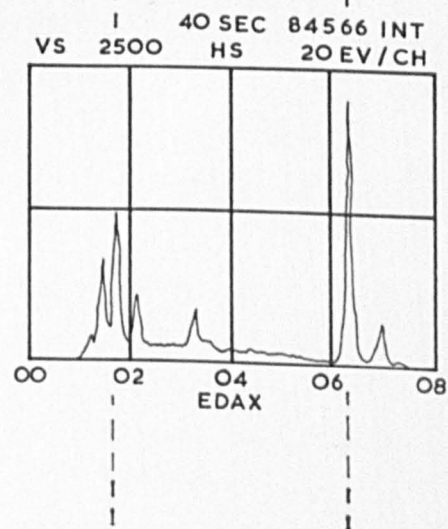
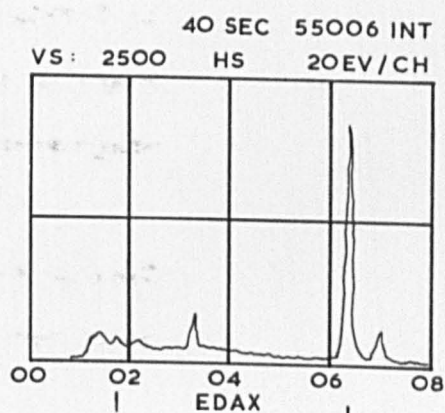
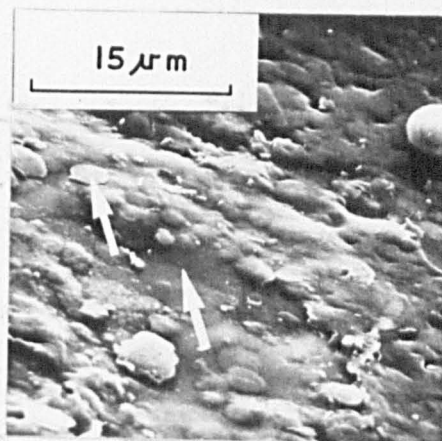
a



Al
Mg Si

Fe

b



Al
Mg Si

Fe

1

2

Plate 6.15 Summary of E.D.A.X analysis of progressive hematite development.

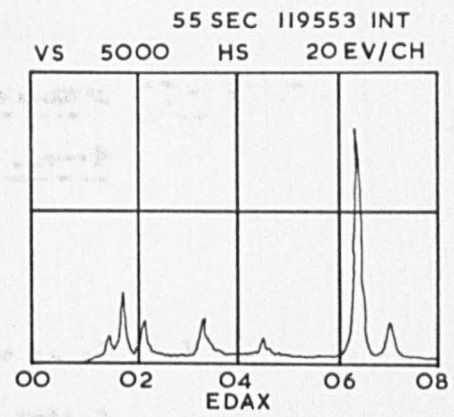
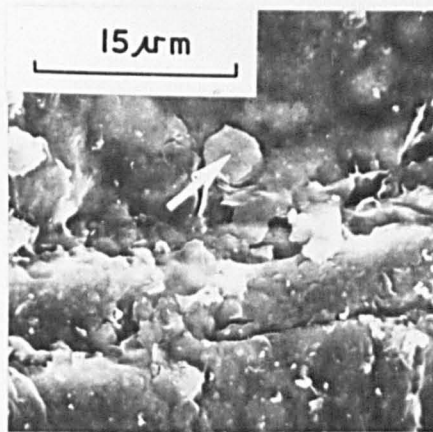
- A. Early stage of hematite development, pseudo-hexagonal flakes separating from cleavage surfaces. Note that Fe is enriched in the adjacent EDAX trace in comparison to Mg, Al, and Si.

- B. More mature stage of hematisation. Note that Mg, Al and Si are still quite high.

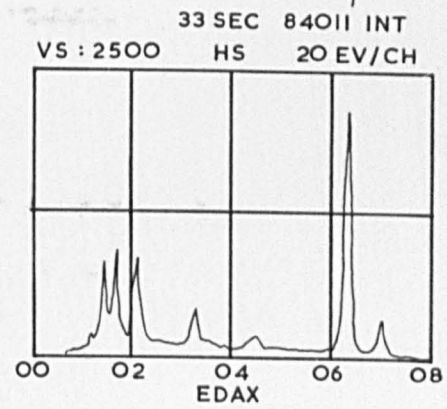
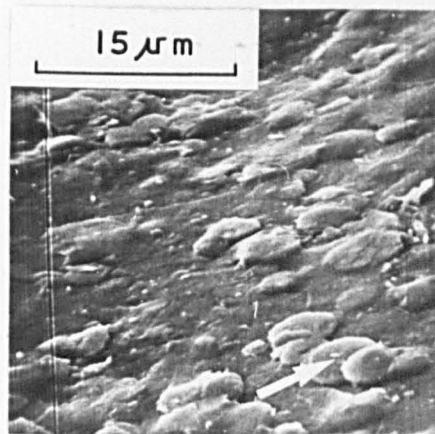
- C. Final stage of hematisation, when flake is totally pseudomorphed by hematite. Note that Mg, Al, and Si peaks are very much reduced.

In all of the above EDAX figures, the analysis has been performed at sites indicated by arrows (representing sites considered to be locations of hematite development).

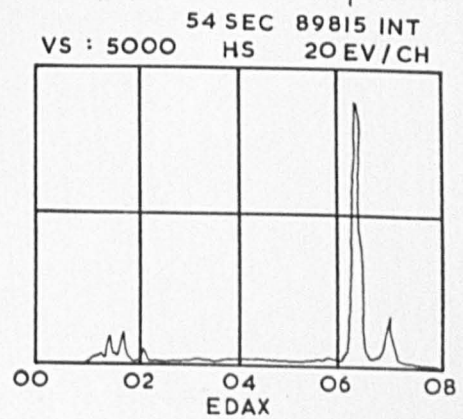
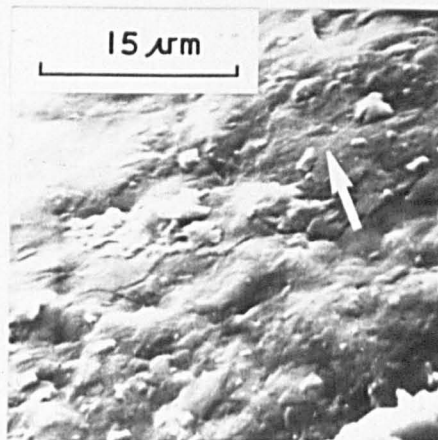
a



b



c



Al
Mg Si

Fe

CHAPTER 7

Figure 7.1 Logged section through the Counter Head Siltstone sequence
showing the distribution of various forms of carbonate
accumulation. (letters refer to the text).

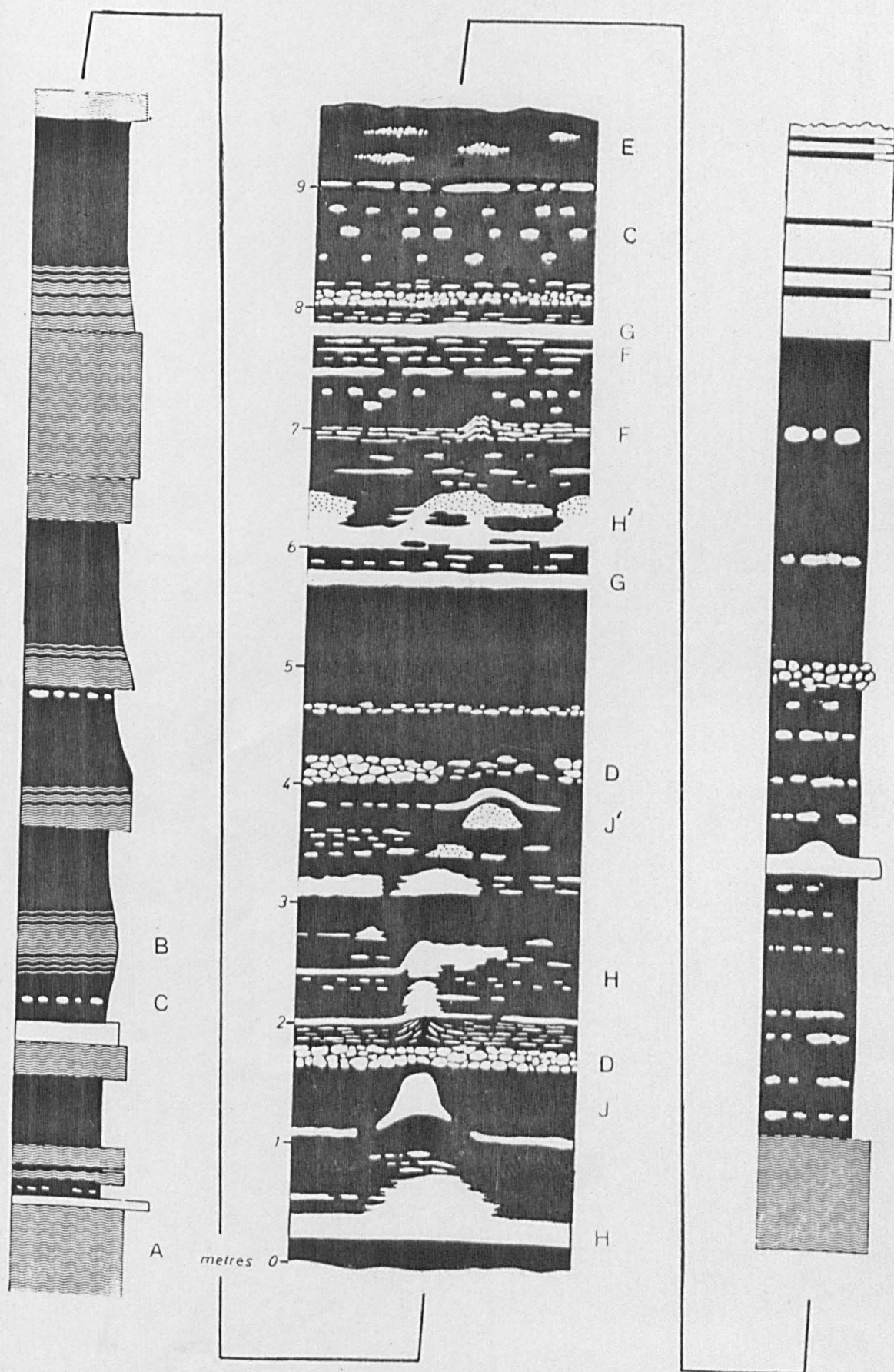


Plate 7.1 Calcrete development at Quarryhead, field
appearance.

- A. General form of calcrete profile showing the range of nodule size, and density of development.
- (a) mature stage of development,
 - (b) immature stage of development.
- (scale: 1m)

- B. Mature stage of nodule development.

Note that nodules coalesce into vertical 'pipe like' elements (a, b).

Overlain by floodplain siltstones with few nodules.

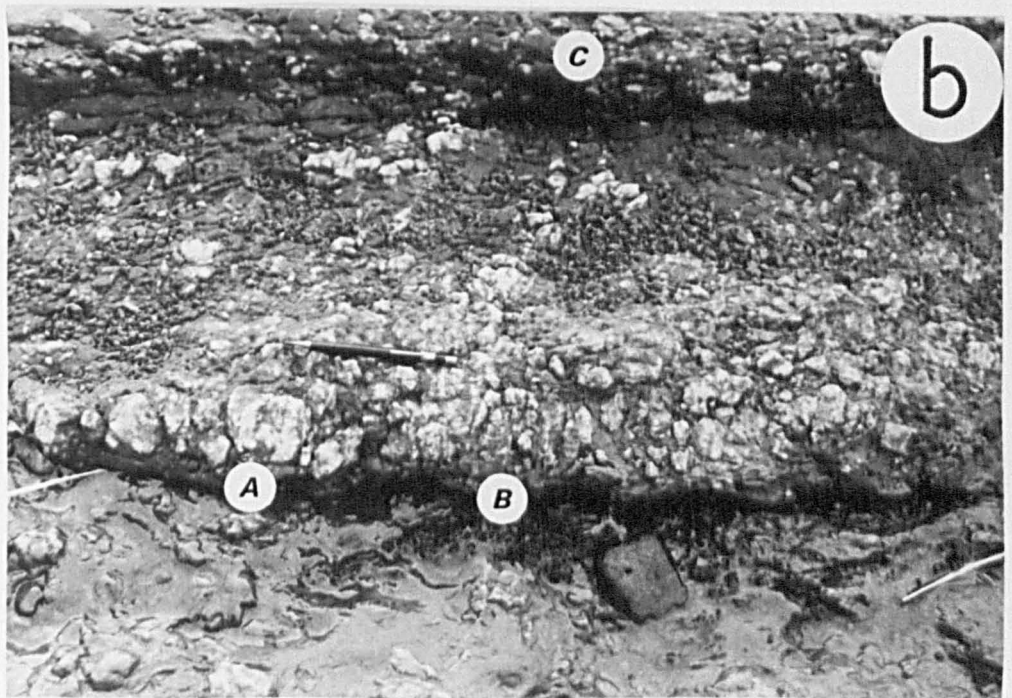
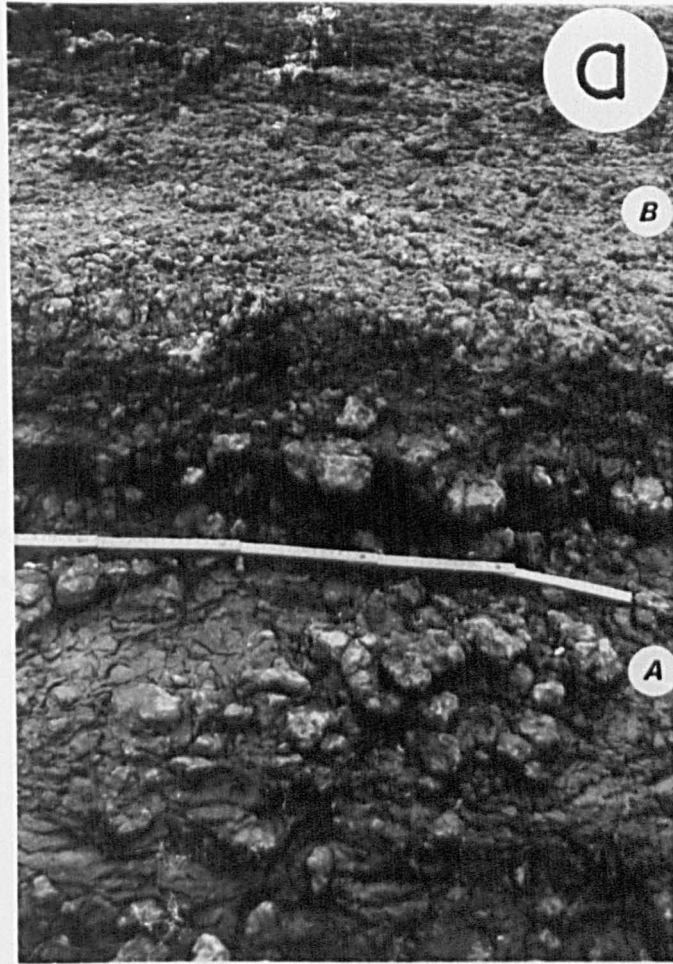


Plate 7.2 Stages of calcrete development at Quarryhead and
at Crovie.

- A. Development of prismatic peds.
- B. Initiation of carbonate accumulation within
 peds.
- C. Localised development of small nodules.

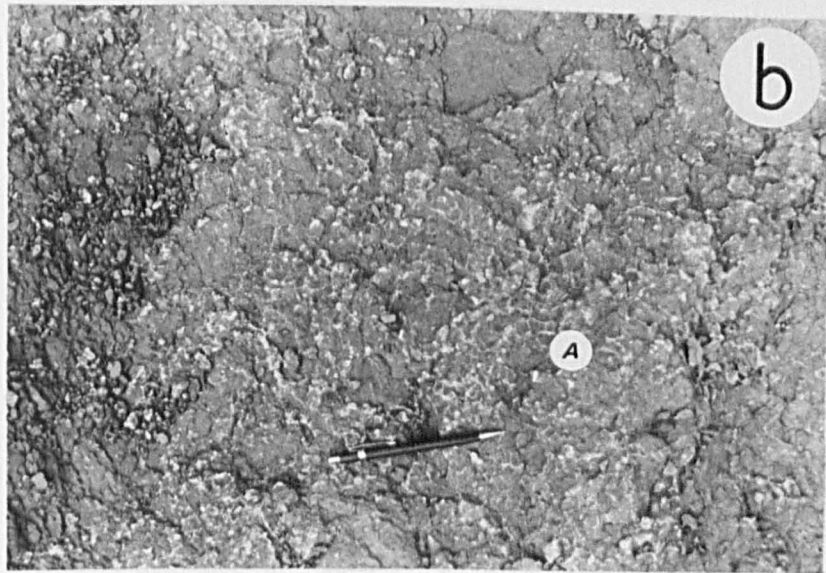
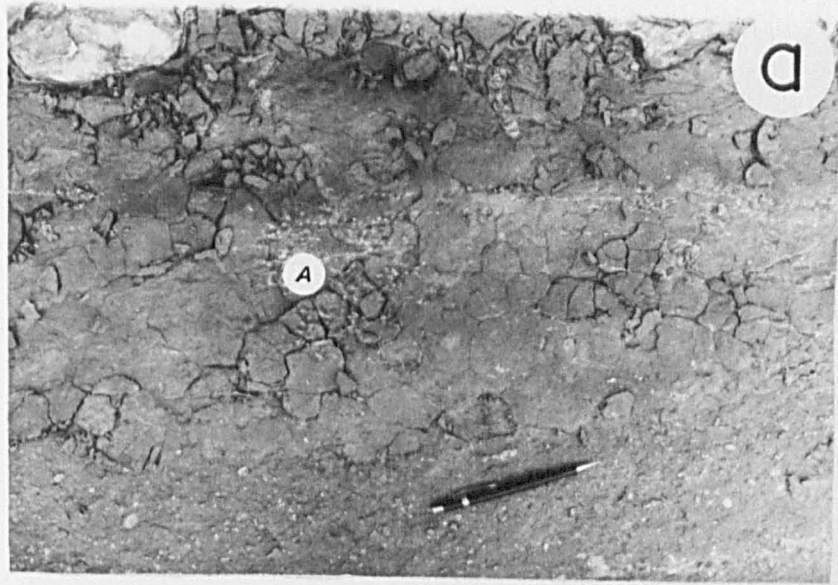


Plate 7.3 Stages of calcrete development at Quarryhead and
at Grovie.

- A. An uncommon stage where shrinkage cracks between
peds are infilled by carbonate, producing a brecciated
appearance.

- B. Original small nodules enlarge and begin to coalesce.
Note slight vertical stacking of nodules (a), conforming
to the original ped structure.

- C. Gross nodule enlargement, until most individuals
are in close contact. (scale 15 cm)



Plate 7.4 Counter Head type of calcrete development.

- A. Continuous thin sheets of carbonate (type F).
- B. Continuous thin sheets of carbonate (type F).
- C. Isolate elliptical nodules generally occurring in persistent sheets (type C).
- D. Continuous thin sheets of carbonate (type F)
- E. Thin discontinuous sheets of carbonate interbedded with clastic sediment (types A and B).
- F. Isolate elongate nodules (type C).

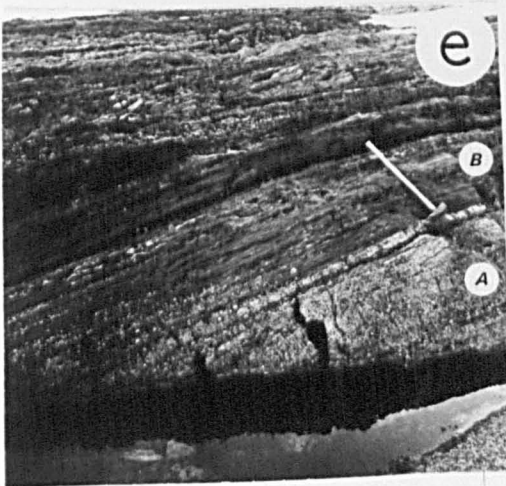
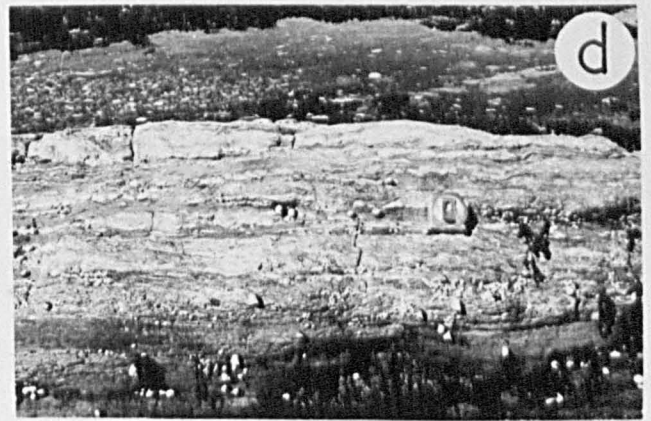
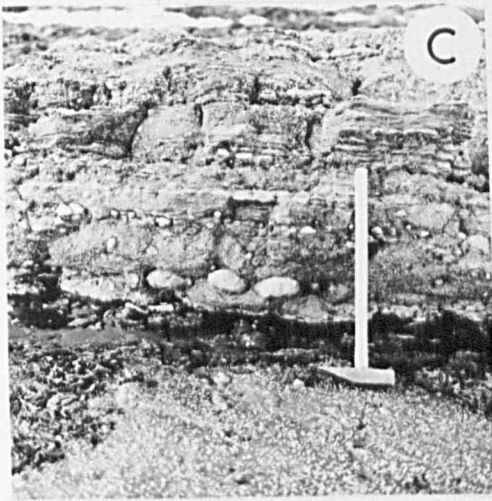
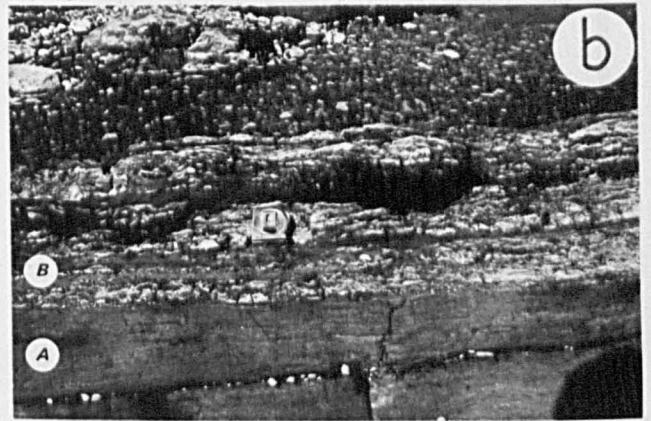
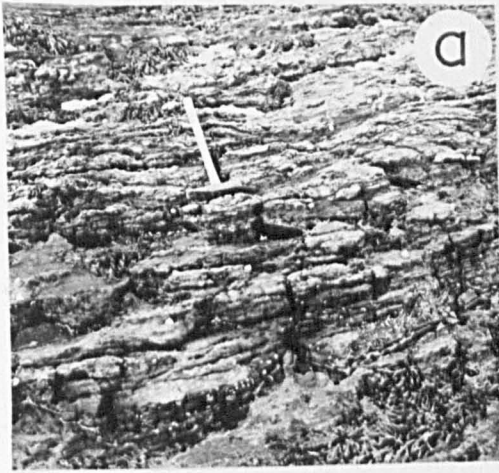


Plate 7.5

Counter Head type of calcrete development.

- A. Sheet of carbonate with well-developed desiccation polygons.
- B. Clustered nodules (type E).
- C. Massive 'knoll' type of carbonate accumulation. (type H, J).
- D. Massive 'knoll' type of carbonate development, note the displacement of the overlying siltstone (a).
- E. 'Tepee' type small anticline structure within thin sheets of carbonate. (vertical axis arrowed).
- F. 'Knoll' of carbonate with dense development of clustered nodules above (a).

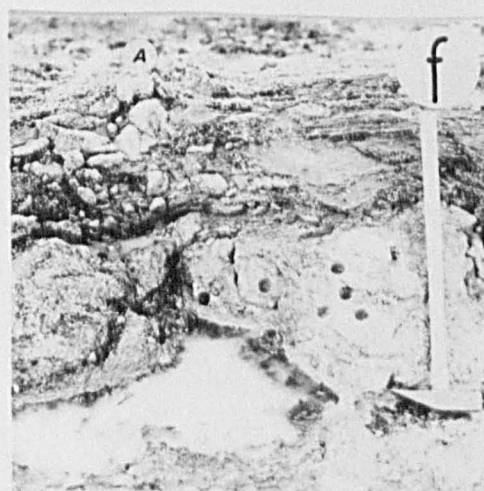
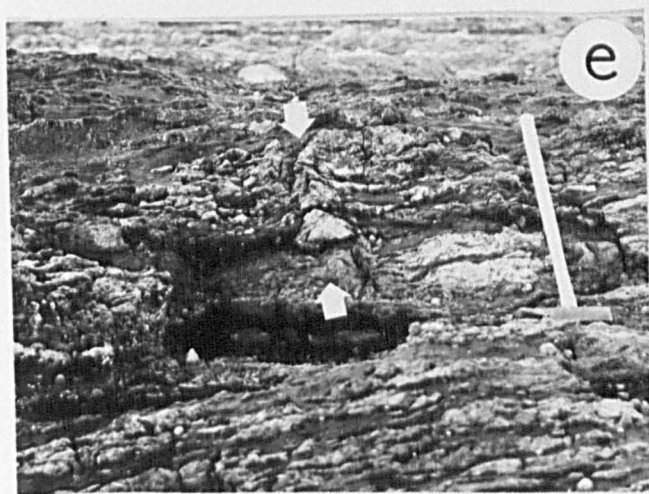
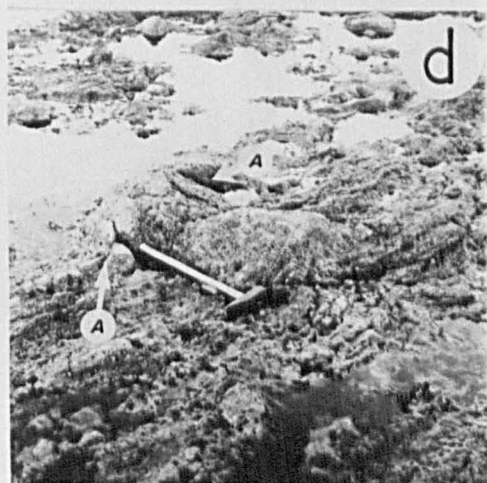
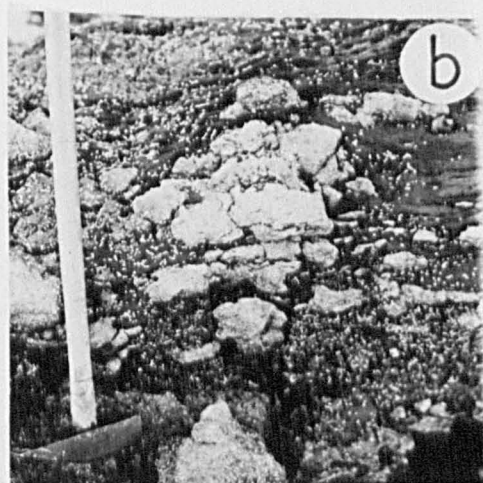


Plate 7.6 Counter Head type of calcrete development.

- A. Isolated 'knoll' laterally adjacent to a single carbonate sheet.

Note that development of the 'knoll' overlies a previous 'knoll' development, and that overlying carbonate development remains unaffected.

- B. Regular spacing of carbonate 'knolls' along a single horizon. (arrows indicate a separation in this instance of approx. 6m).

- C. Carbonate 'knoll' showing overlying clusters of small nodules.

- D. General view of the vertical arrangement of carbonate 'knolls'. Note that several follow in vertical sequence. (width of centre of field approx. 10 m)

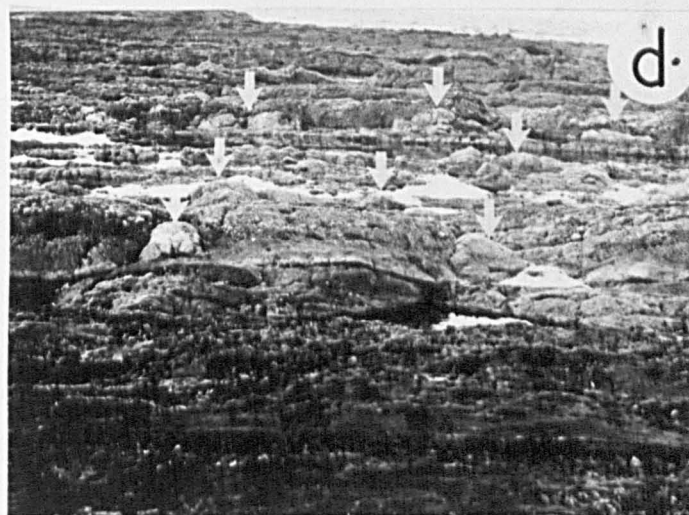
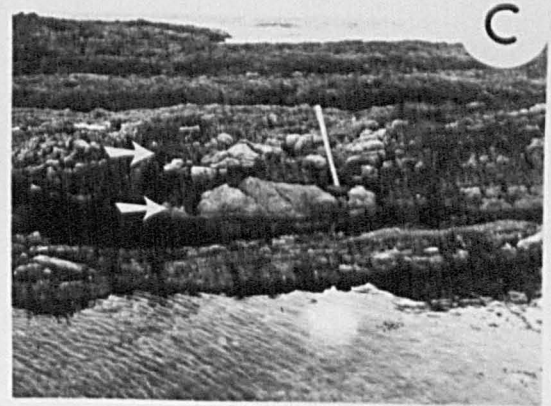
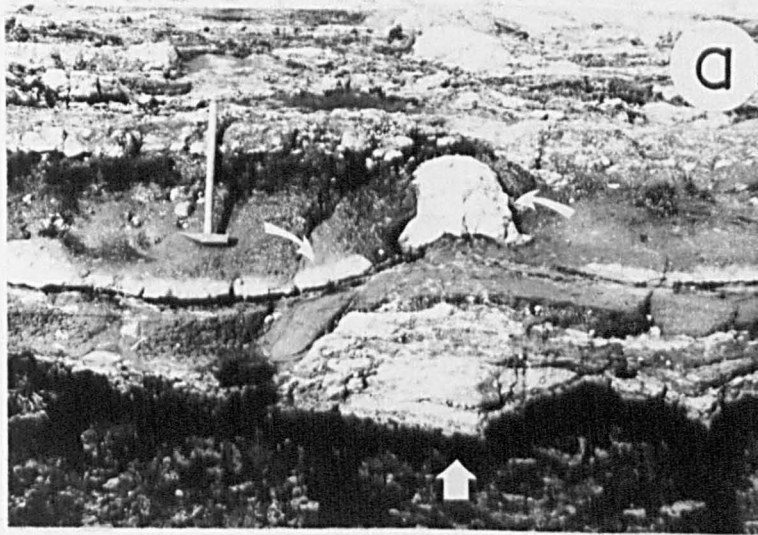


Plate 7.7 Photomicrographs of Quarryhead / Crovie type nodules.

- A. Photomicrograph of nodule areas (A), and crystallaria (B).
Note the indistinct nature of some of the nodule
boundaries.
- B. Illustration of several stages of nodule development:
 (A) early, finely crystalline, iron stained nodule
 areas.
 (B) later more coarsely crystalline carbonate, increasig
n nodule size. Note retraction fissures.
- C. Multiple phases of nodule development:
 (A) nodule areas,
 (B) crystallaria,
 (C) early crystallaria,
 (D) retraction fissures, latest stage.
- D. Cross cutting retraction fissures (A).

(scale in all cases : field width 1cm)

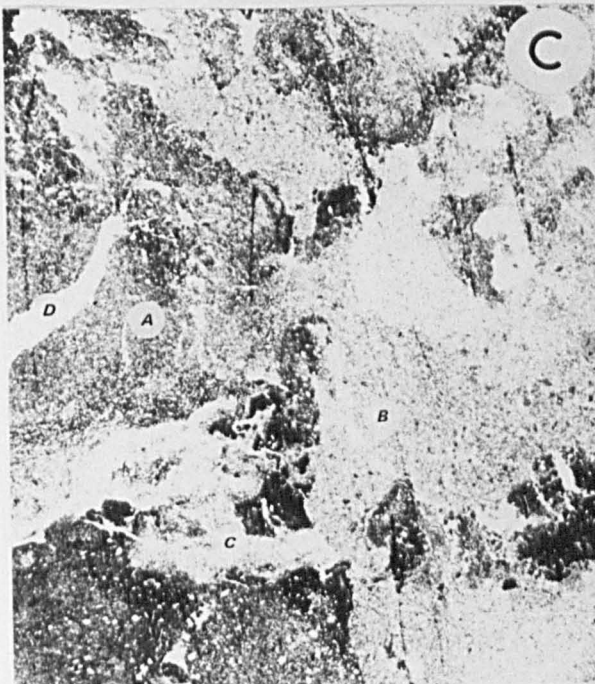
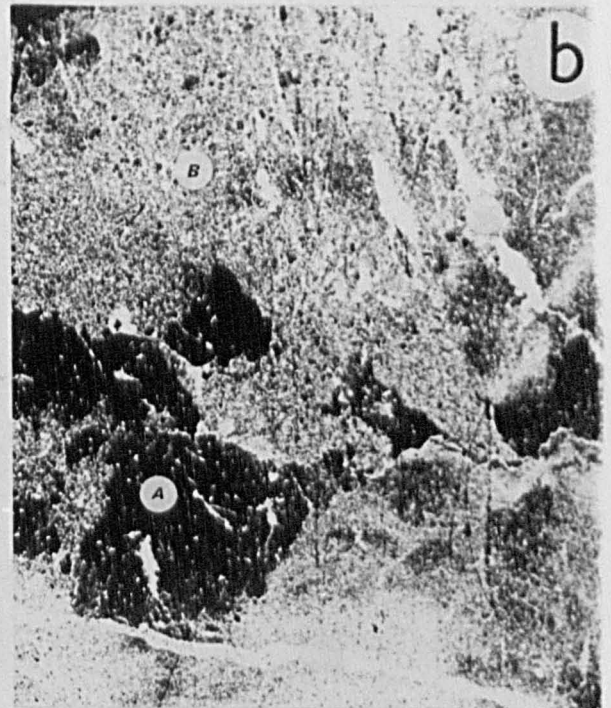
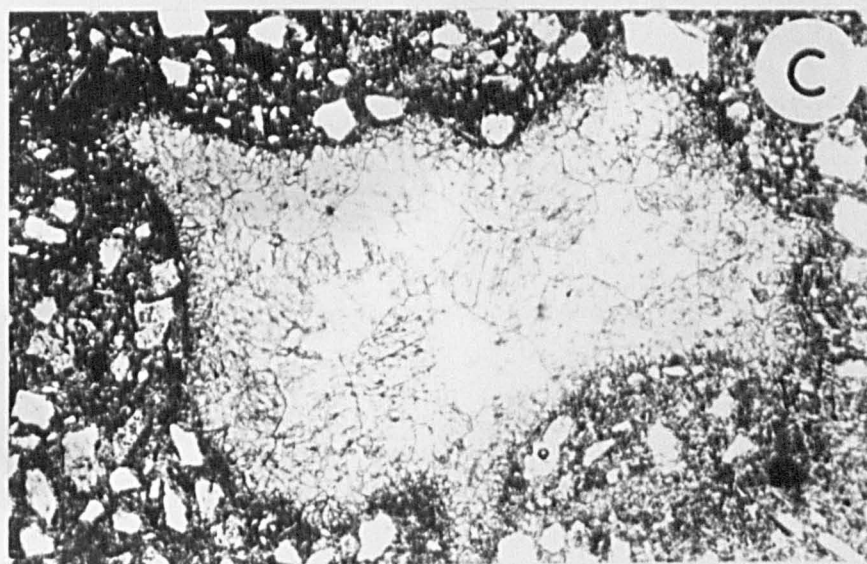
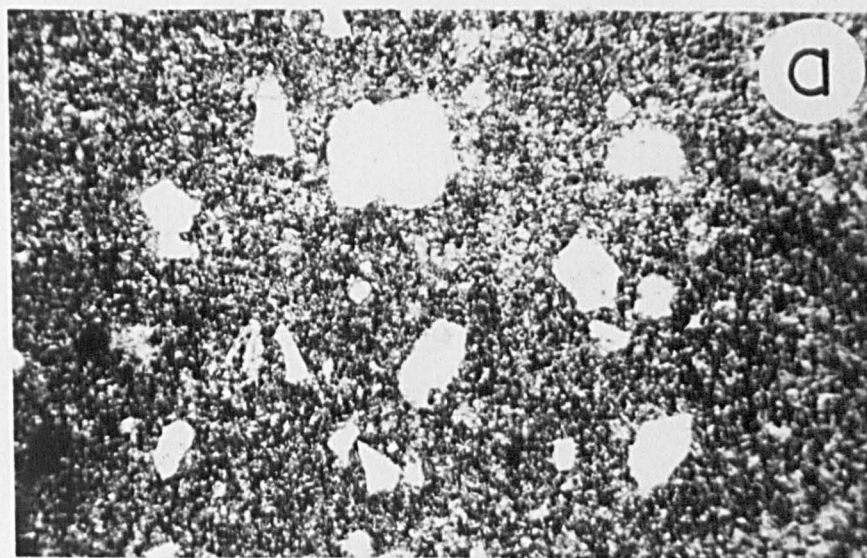


Plate 7.8 Photomicrographs of calcrete textures.

- A. Detrital quartz grains widely displaced by
fine grained carbonate cement.
(field width 1mm)

- B. Biotite mica 'exfoliated' by carbonate cement,
also note the fretted quartz grains.
(field width 1mm)

- C. Fenestral void infilled by sparry calcite
following an initial drusy spar development.
(field width 1mm)



A. General form of types A and B carbonate.

Carbonate (C) occurs interbedded with siltstone (S).
(natural size)

B. Portion of a brecciated horizon.

Initial carbonate cemented areas (X), upon fracturing, the voids become partially infilled by sediment (Y) and then sparry calcite (Z).
(field width 2mm).

C. Fenestral void infilling.

Note the presence of a dark zone of inclusions around the perimeter of the cavity. At (X) there is a suggestion of the inclusion patterns recording original euhedral drusy calcite.
(field width 1mm)

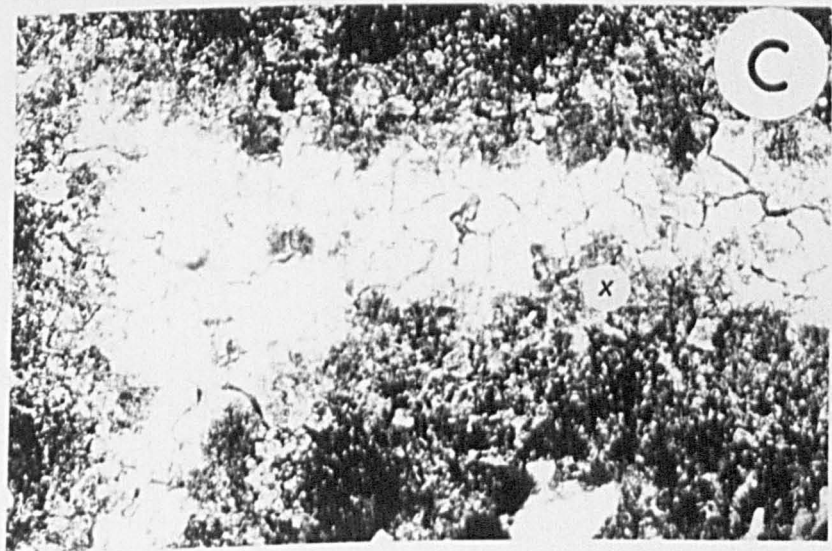
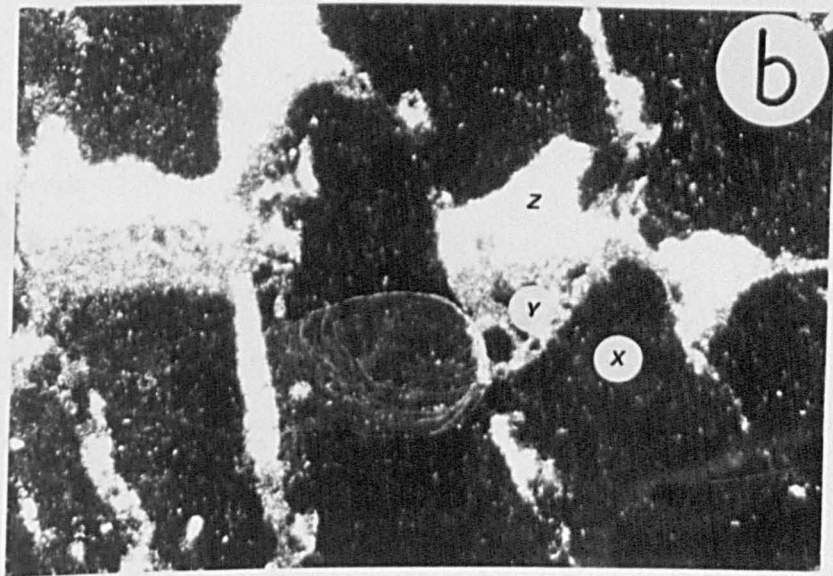
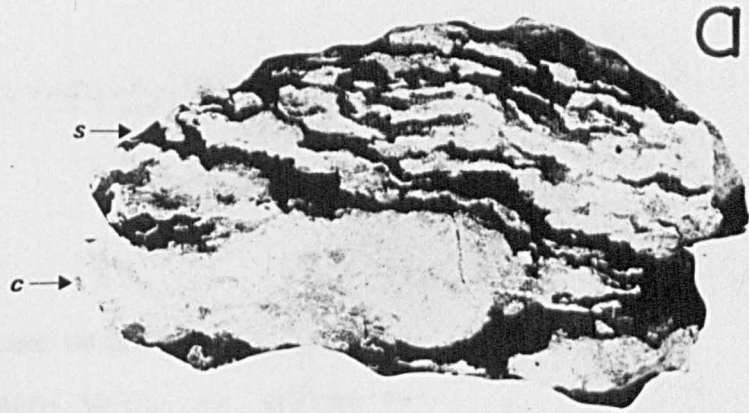


Plate 7.10 Photomicrographs of calcrete textures.

- A. Brecciated calcrete showing the early cemented sediment with floating quartz grains (A), fractured, and then recemented by coarser calcite (B).
(field width 2mm)
- B. Lining of sheet crack.
(A) original carbonate cemented sediment,
(B) calcite with dense inclusion patterns, but with evidence of crystal boundaries formed during a later phase of recrystallisation,
(C) evidence of drusy spar preserved by inclusion pattern,
(D) final coarse sparry calcite infilling remaining void.
(field width 2mm)
- C. Lining of sheet crack.
(A) original carbonate cemented floodplain sediment.
(B) pore filling calcite with rich inclusion pattern.
Inclusion pattern is particularly dense in narrow parts of the void.
(field width 2mm)

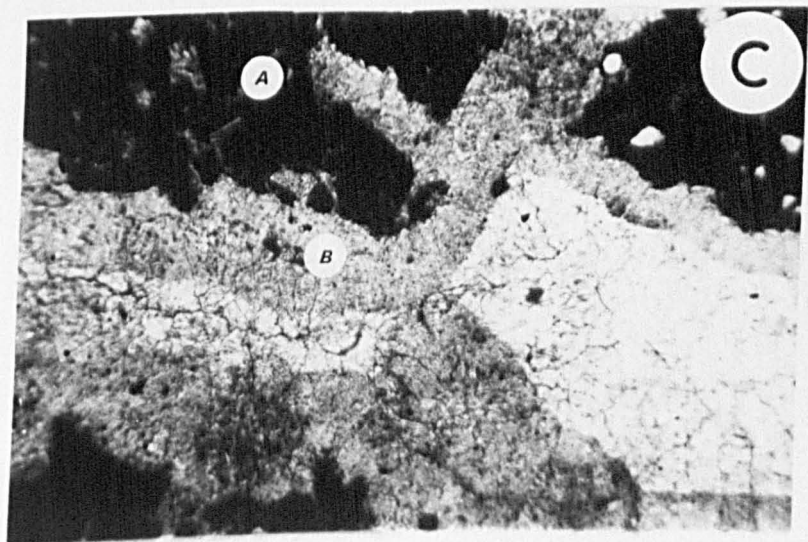
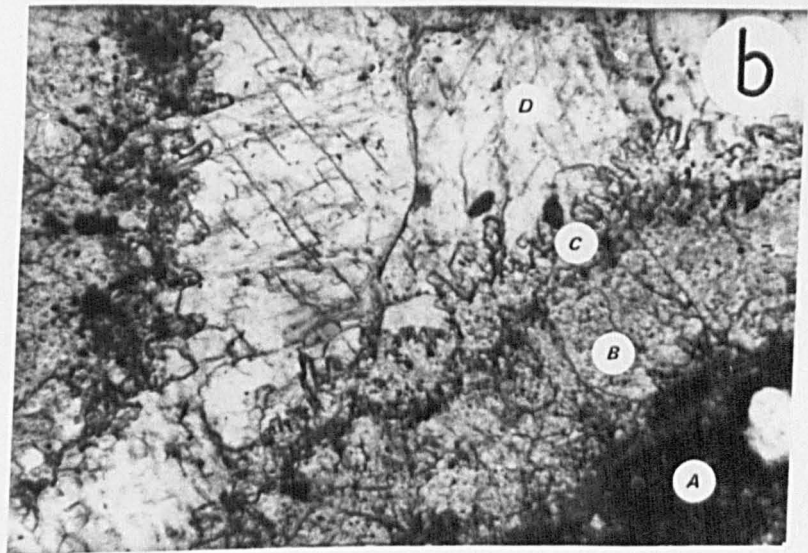
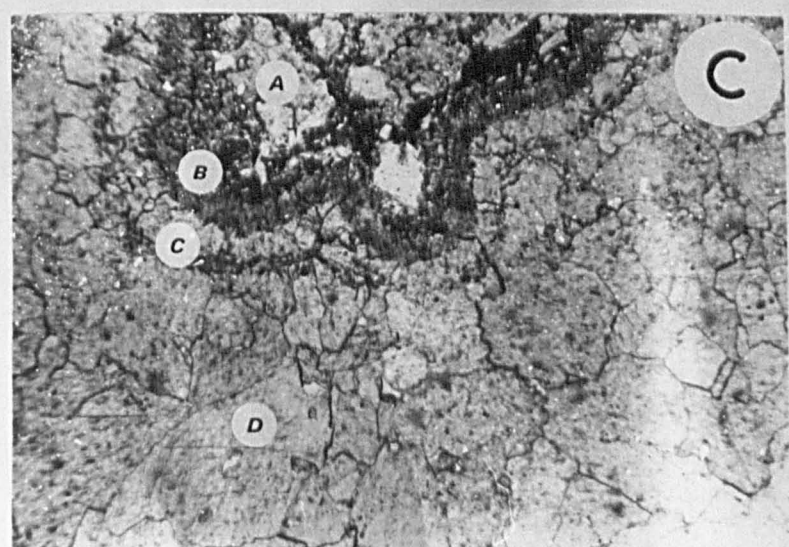
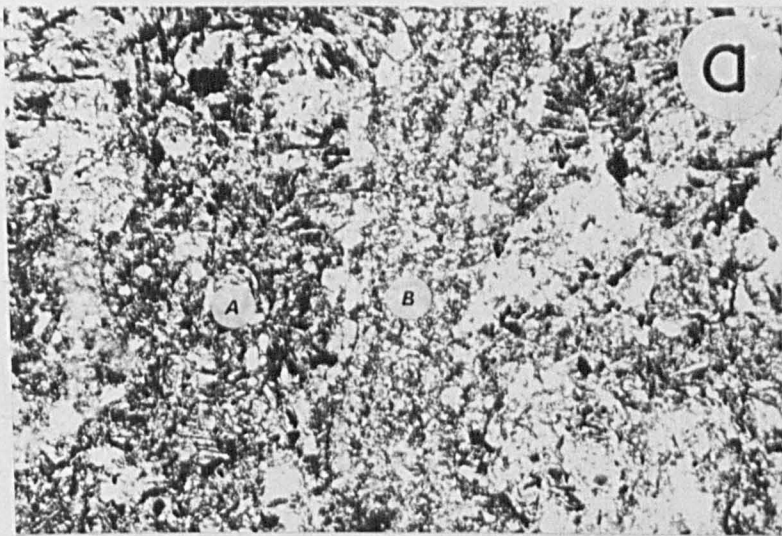
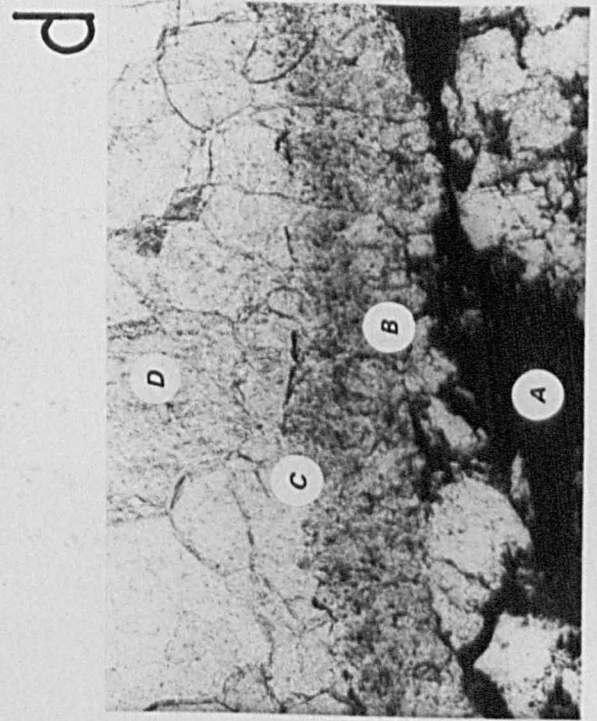
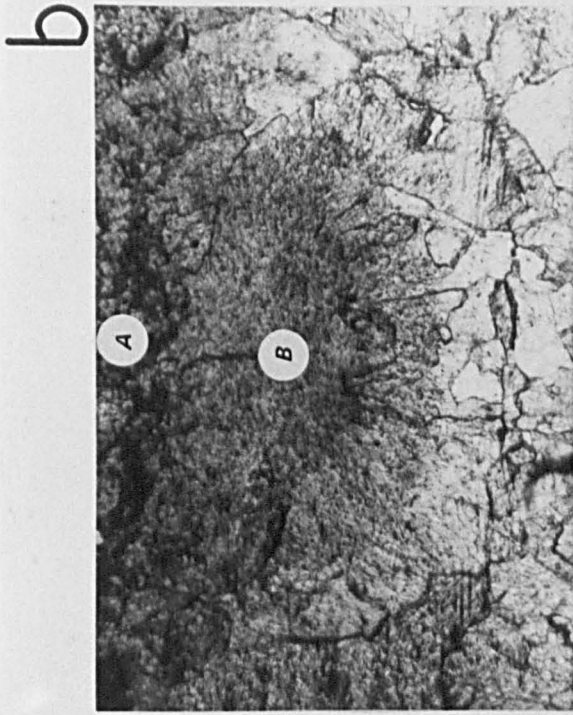


Plate 7.11 Photomicrographs of calcrete textures.

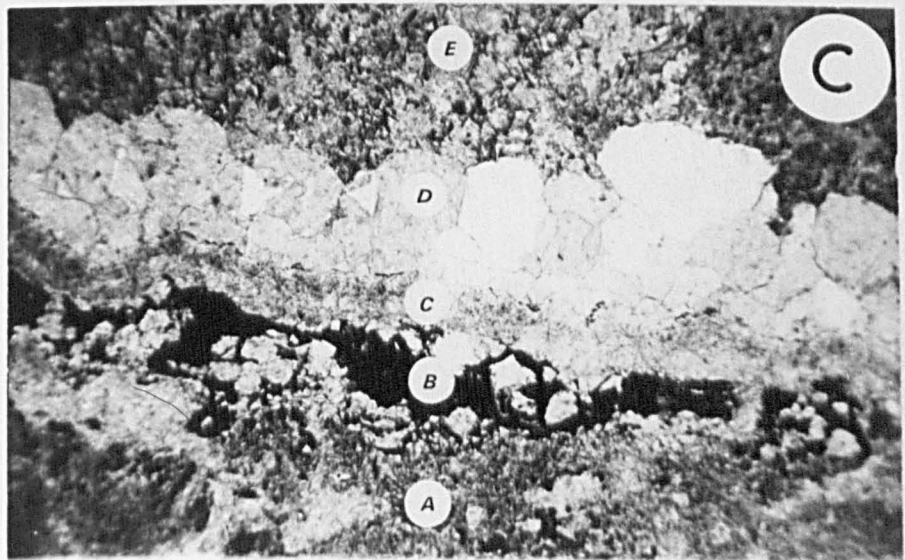
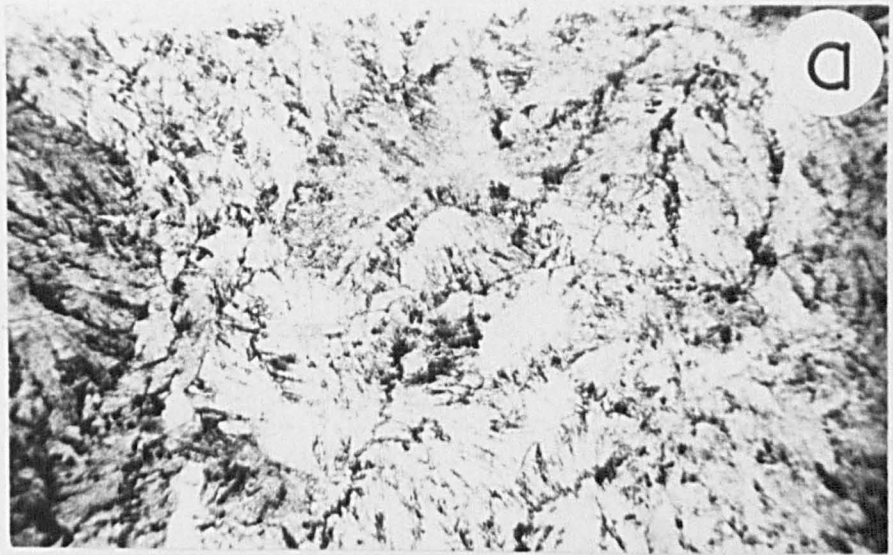
- A. Section of a crystallaria showing the host nodule (A), and the crystallaria (B). Note the crude lamination developed within the crystallaria.
(width of field 2mm) (crossed polars).
- B. Section through a fenestral void showing host sediment (A), an initial drusy cavity lining (B), and a final stratified sediment infilling to the void (C).
(field width: 3mm)
- C. Detailed view of inclusion pattern within a cavity lining. Note the preservation of several stages of growth indicated by the parallel zones of inclusions (C) and (B).
(field width 0.75 mm)



- A. Dripstone / microstalactite type of cementation preserved by inclusions within the calcite.
- (A) floodplain sediment,
 - (B) microstalactite picked out by inclusions,
 - (C) note second generation of inclusions.
- (field width 2mm)
- B. Detail of a dripstone feature. Note that the recrystallisation of the carbonate is evident from the crystal boundaries passing unaffected through the inclusion zones.
- (field width 0.5 mm)
- C. Asymmetric form of the cavity lining cement.
- (field width 2mm)
- D. Detailed study of inclusion zone showing:
- (A) host sediment,
 - (B) inclusion zone with clearly defined crystal boundaries passing through,
 - (C) layer of fine sediment, possibly a cutan formed prior to final sparry calcite development.
- (field width 0.75 mm)



- A. Fibrous ferroan dolomite occurring as a very late stage cavity infilling in sheet cracks.
(field width 1mm)
- B. Same field as above, crossed polars.
- C. Detail of paragenesis of cements:
- (A) carbonate cemented host sediment,
 - (B) relatively thick fine grained pellicle or 'cutan'. (Brewer 1964)
 - (C) zone of inclusions, also with a further pellicle or 'cutan' of fine sediment,
 - (D) early cavity lining of calcite,
 - (E) latest phase of cavity infilling by ferroan dolomite.
- (field width 2mm)



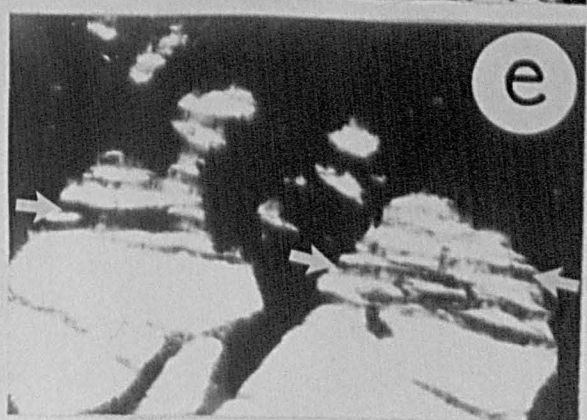
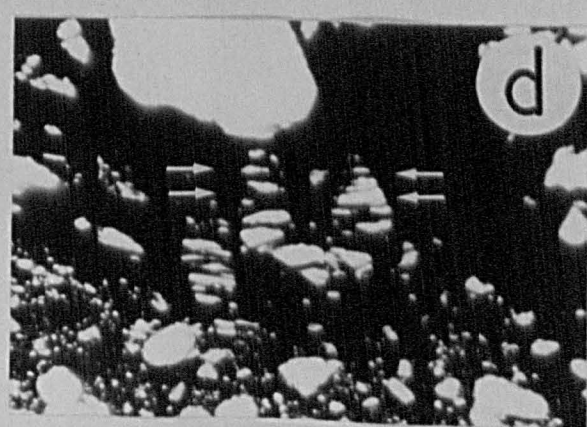
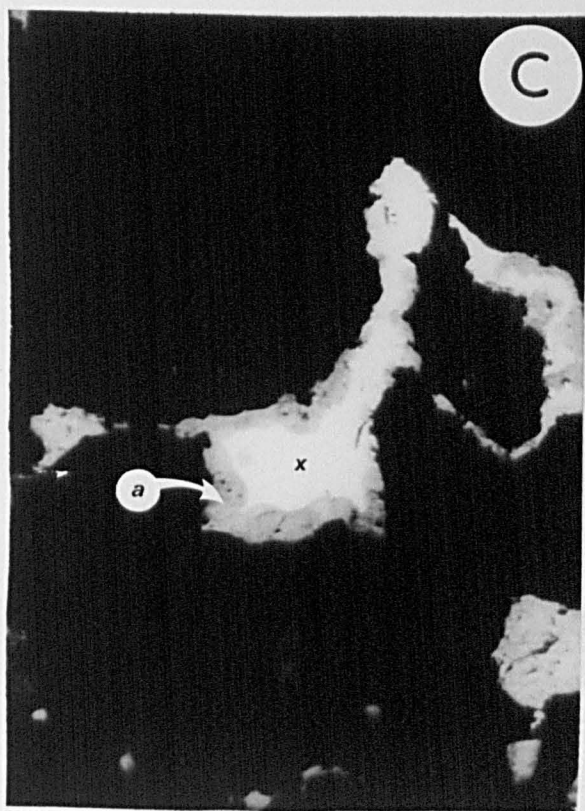
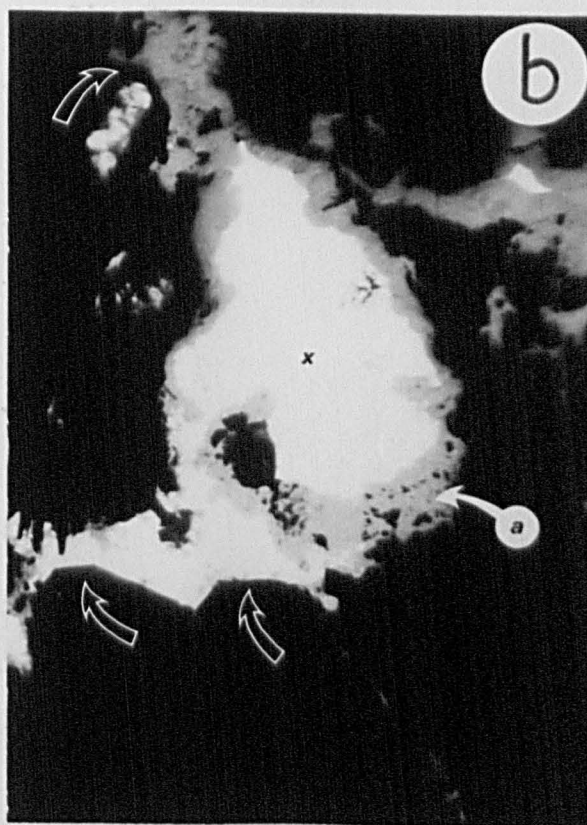
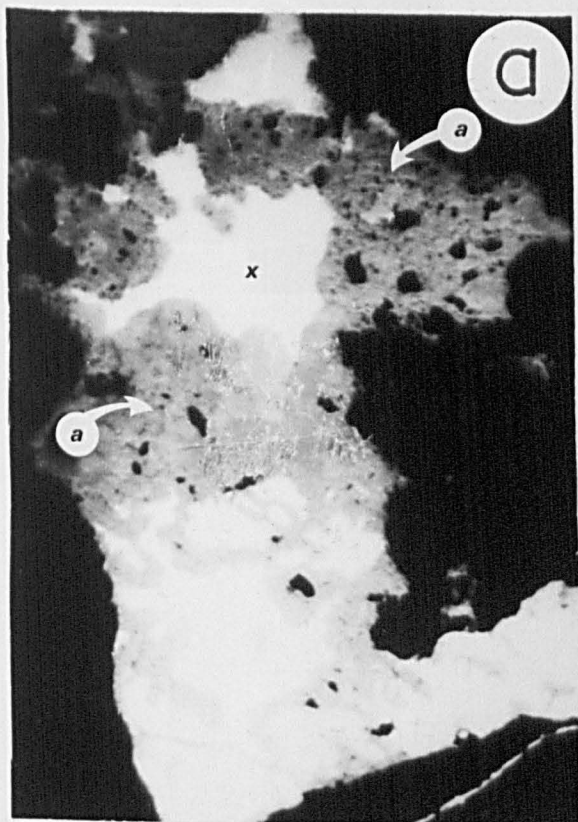


Plate 7.15 Summary of electron probe analysis of psilomelane and iron oxide cements in the Pennan Sandstone.

- E. Electron image showing the distribution of psilomelane (light), and iron oxide (dark). (field width 0.1 mm)

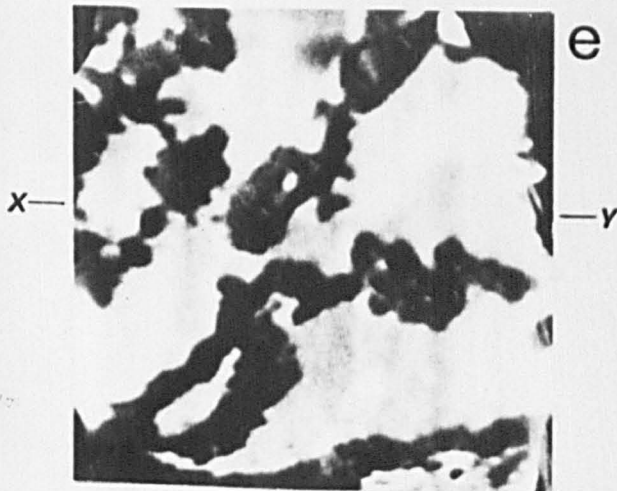
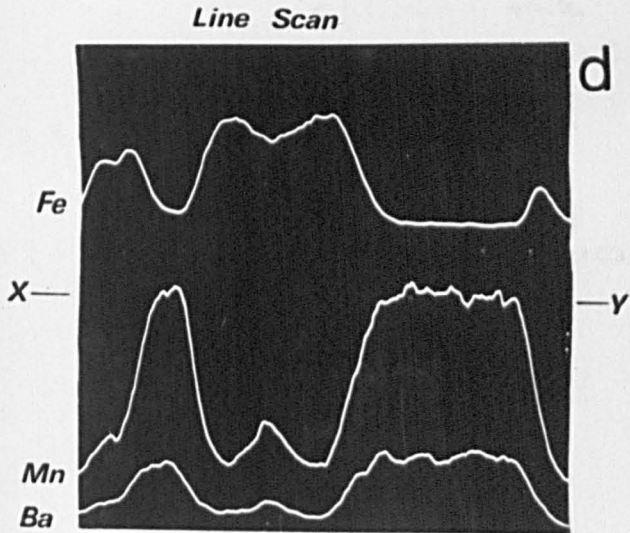
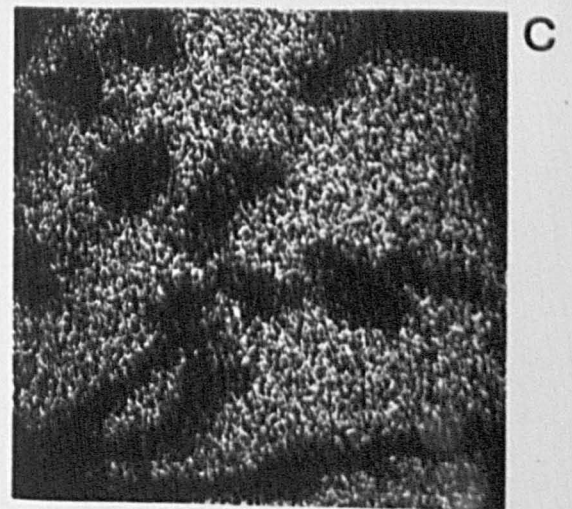
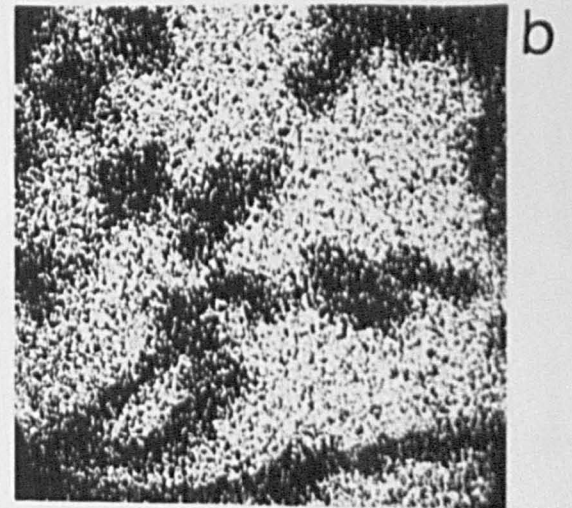
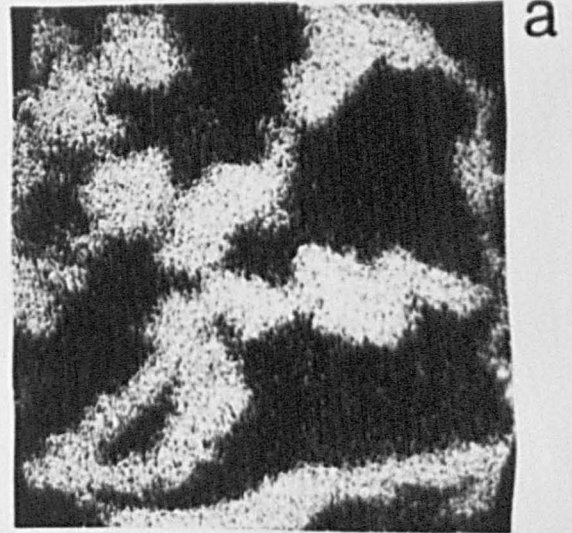
- A. X-ray image showing the relative distribution of Fe.

- B. X-ray image showing the relative distribution of Mn.

- C. X-ray image showing the relative distribution of Ba.

- D. Line scan from X - Y on electron image demonstrating the abundance of Fe / Mn / Ba , and indicating the relationship between Mn and Ba, in contrast to the inverse relationship of Fe to Mn / Ba.

X-Ray Images



Electron Image